COMPUTER MODELING OF THE ST. LOUIS PARK AREA EMPLOYING THE MODIFIED USGS GROUND-WATER FLOW MODEL

REPORT ON WORK COMPLETED
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This document includes information describing ERT's work on computer modeling of the St. Louis Park area completed subsequent to the April 1983 report, "Recommended Plan for a Comprehensive Solution to the Polynuclear Aromatic Hydrocarbon Contamination Problem in the St. Louis Park Area". The document includes two sections. The first is a response to comments of the Minnesota Pollution Control Agency (MPCA) concerning the ground-water modeling described in the April 1983 report. The second is a description of revisions made to the USGS model that employ revisions made by Torak (1983) to the USGS computer program.

Response to MPCA Comments

In meetings held in August 1983, Minnesota Pollution Control Agency personnel raised a number of questions concerning the ground-water model of the St. Louis Park area that was developed and used by ERT. The following paraphrases the questions from the state and responds to these questions.

1. The value of K/n, the parameter which determines ground-water travel velocity, differs greatly between the Prairie du Chien and the Jordan formations. ERT used an average value which is an unconservative approach.

The values of K and n are imperfectly known for the Prairie du Chien-Jordan aquifer. We used values of n = 15% (from Hickok 1981) and K = 37.2 ft/day (computed from transmissivity values given by Norvitch et al., 1973. Norvitch et al. give the value 5.6% for n for the Prairie du Chien alone. A value of K = 33.8 ft/day may be inferred from Reeder et al. (1976) who give a value of the transmissivity of 38,000 gpd/ft for the Prairie du Chien alone in an area where the formation is 150 feet thick. Other available data do not give transmissivity or hydraulic conductivity information for the Prairie du Chien formation alone: other data treat the properties of the aquifer unit, which includes both the Prairie du Chien and the Jordan.

The ratio of K/n for the Prairie du Chien to K/n for the Prairie du Chien-Jordan is 2.4 based on the numbers above. The speed of ground-water travel in the Prairie du Chien would be 2.4 times faster than that predicted by ERT if the more conservative numbers are used. We have examined the consequences of such a change on our cost estimates and conclusions. Changes to the pertinent tables in Chapter 6 of the ERT report are attached.

ERT employed average aquifer properties, rather than properties for the Prairie du Chien alone, because there is relatively little difference in the resulting K/n values, and because there are fewer data to describe the hydraulic conductivity and transmissivity of the Prairie du Chien formation than there are data describing the entire aquifer. The numbers employed reflect average aquifer properties and do not account for the possible range in hydraulic conductivity values. The Prairie du Chien-Jordan transmissivity varies by a factor of 5 according to data in Norvitch et al. Transmissivity is the product of hydraulic conductivity and the aquifer thickness, thus the variation in hydraulic conductivity may be somewhat less. Nevertheless, there is considerable variation in hydraulic conductivity over space. Over long transport distances, contaminant will experience different hydraulic conductivities. Thus, the net contaminant travel will reflect average aquifer properties to some extent. The factor of 2.4 difference discussed above is within the uncertainty range one would expect to see in the aquifer properties. Indeed, variation of hydraulic conductivity within an order of magnitude is reasonable for an aquifer like the Praire du Chien-Jordan (Mercer et al. 1983, and Fray 1975).

The change in the value of K/n will change the time for contaminants to travel to presently uncontaminated wells, and will thus change the present value costs reported in the ERT report. The following are tables from ERT's report that are changed by the change in present value. Not all corrections to the report have yet been computed; however, the cost of monitoring municipal wells will increase, but not sufficiently to alter significantly the final total costs or selection among drinking water supply options.

TABLE 6-5

PREDICTED MUNICIPAL WELL CLOSURES AND RESULTING SUPPLY SHORTFALLS

	Contaminated Wells Remain Closed (See Section 6.4)		Selected Contaminated Wells are Treated (see Section 6.3)	
	Predicted Closure Timing[a]	Supply Shortfall, Millions of Gallons per Year[b]	Predicted Closure Timing[a]	Supply Shortfall Millions of Gallons per Year[b]
[redacted]	0-5 years	40	0-5 years	40
	Now	90	Now	90
Non-responsive	0-5 years	270	0-5 years	270
	Never	0	Never	0
	Never	0	Never	0
	Now	50	Now	50
	Now	240	Now	240
Subtotals		690		690
[redacted]	10-20 years	420	20-30 years	420
	15-25 years	30	30-40 years	30
NON-RESPONSIVE	20-30 years	130	40-100 years, if ever	130
	40-60 years	70	Never	0
	20-30 years	380	40-100 years, if ever	380
	60-100 years	380	Never	0
	25-40 years	90	40-100 years, if ever	90
	60-90 years	30	Never	0
Subtotals		1530		1050
Totals		2220		1740

Notes:

(a) Based on a criterion for noncarcinogenic PAH and heterocyclic PAH at the low end of the recommended range (4 micrograms per liter).
(b) Based on historic average pumping rates shown in Tables 6-1 and 6-2.

TABLE 6-8

PREDICTED MUNICIPAL WATER SUPPLY SHORTFALLS

IN ST. LOUIS PARK AND EDINA TO BE MET BY TREATING CONTAMINATED WELLS

(Millions of Gallons per Year)

	Best Case Prediction		Worst Case Prediction	
Year	St. Louis Park	Edina	St. Louis Park	Edina
1983	380	0	690	0
1988	690	0	690	0
2003	690	0	690	420
2013	690	0	690	450
2023	690	420	690	1050
2043	690	450	690	1050

TABLE 6-9

ESTIMATED COSTS FOR DRINKING WATER TREATMENT AS AN END-USE CONTROL

(Revised 11/84)

WORST-CASE CONTAMINANT MIGRATION:

Well	Year Required	Capacity, Gallons per Minute[a]	Flow Rate, Millions of Gallon per Year[a]	Existing Iron Removal Plant	Present Value Cost, $ Millions: Powdered Activated Carbon Or Ozone Injection[b]	Present Value Cost, $ Millions: Granular Activated Carbon Treatment[c]
SLP10 & SLP15[f]	1983	2200	300	Yes	0.28-0.76[d]	1.4-5.5[d]
SLP6	1983	1200	300	Yes	0.10-0.20	1.2-3.5
E2	2003	800	400	Yes	0.10-0.20	0.41-0.94
E4 & E6	2023	1850	580	Yes	0.04-0.09	0.20-0.68
				Study Costs[e]	0.8-1.9	0.1-0.2
				Totals	0.8-1.8	3.2-10.8

BEST-CASE CONTAMINANT MIGRATION:

Well	Year Required	Capacity, Gallons per Minute	Flow Rate, Millions of Gallon per Year	Existing Iron Removal Plant	Present Value Cost, $ Millions: Powdered Activated Carbon Or Ozone Injection	Present Value Cost, $ Millions: Granular Activated Carbon Treatment
SLP10 & SLP15[f]	1983	2200	300	Yes	0.28-0.76	1.4-5.5[d]
SLP6	1988	1200	300	Yes	0.18-0.44	0.9-2.7
E2	2013	800	400	Yes	0.06-0.12	0.2-0.6
E4 & E6	never					
				Study Costs[e]	0.2-0.4	0.1-0.2
				Totals	0.7-1.7	2.6-8.8

Notes:

(a) From Appendix G section G.2.
(b) Lower bound represents PAC injection at 2 milligrams per liter. Upper bound represents ozone injection at 2 milligrams per liter.
(c) Lower bound represents 7.5 minute contact time and equilibrium breakthrough time, upper bound represents 30 minute contact time and 1-year breakthrough time.
(d) Includes cost of $50,000 to $100,000 to clean out well SLP10, which is currently sand-locked.
(e) Includes $0.1 million to develop a reliable and inexpensive performance monitoring technique, plus costs of additional studies required to investigate the design of treatment alternatives. (See Appendix G for details).
(f) Pumping of SLP17 at 100 million gallons per year is assumed to help meet supply shortfalls.

TABLE 6-10

PREDICTED MUNICIPAL WATER SUPPLY SHORTFALLS

IN ST. LOUIS PARK AND EDINA TO BE MET BY

PROVIDING ALTERNATE WATER SUPPLY SOURCES

(Millions of Gallons per Year)

	Best Case Prediction	
Year	St. Louis Park	Edina
1983	380	0
1988	690	0
1998	690	420
2008	690	450
2013	690	960
2023	690	1050
2033	690	1120
2073	690	1150
2083	690	1530

	Worst Case Prediction	
Year	St. Louis Park	Edina
1983	690	0
1993	690	420
1998	690	450
2003	690	1050
2008	690	1120
2043	690	1530

TABLE 6-11

PRESENT VALUE COSTS FOR NEW MT. SIMON-HINCKLEY WELLS

(Revised 11/84)

Well	Discount Period, Years[a] Worst Case	Best Case	Operating Rate, Millions of Gallons per Year	Present Value Cost, $ Millions(b) Worst Case	Best Case
St. Louis Park					
• First New Well (SLP17)[c]	0	0	400	0.37-0.67	0.37-0.67
• Second New Well	0	5	300	0.67-1.07	0.52-0.84
			700		
Edina[d]					
• First New Well	10	20	400	0.49-0.80	0.30-0.49
• Second New Well	20	30	400	0.30-0.48	0.18-0.30
• Third New Well	60	100	400	0.04-0.07	<0.01
Totals			1200	1.9 - 3.1	1.4-2.3
			1900		

Notes:

(a) Derived from Table 6-10.
(b) Present value cost for 100 years operation at 5 percent effective annual interest rate based on capital cost of $300,000 to $400,000 and incremental operating and maintenance costs of $25,000 to $45,000 per year for pumping 400 million gallons per year.
(c) Costs for SLP17 are operating costs only, since this well is already built. Incremental operating costs are for an additional 300 million gallons per year pumpage compared to the drinking water treatment case.
(d) First, second, and third new wells replace E2, E4 & E6, and E11, respectively. Other well closure shortfalls, which are relatively minor, are made up by heavier pumpage of other wells.

TABLE 6-13

PRESENT VALUE COST OF END-USE CONTROL OPTIONS, INCLUDING COMPLIANCE MONITORING COSTS[d]

(Revised 11/84)

Cost Item	Present Value Cost, $ Millions[a] New Mt. Simon-Hinckley Wells	Treatment With PAC or Ozone	Treatment With GAC
BEST CASE CONTAMINANT MIGRATION			
Capital and Operating Costs[b]	1.4-2.3	0.7-1.7	2.3-8.8
Compliance Monitoring Costs[c]	0.9-1.2	1.0-1.4	1.0-1.4
Total Cost	2.3-3.5	1.7-3.1	3.3-10.2
WORST CASE			
Capital and Operating Costs[b]	1.9-3.1	0.9-2.0	2.9-10.4
Compliance Monitoring Costs[c]	0.9-1.2	1.2-1.5	1.2-1.5
Total Cost	2.8-4.3	2.1-3.5	4.1-11.9

Notes:

(a) Based on 100 years at 5 percent effective annual interest rate.

(b) From Tables 6-9 and 6-11.

(c) From Table 6-12.

(d) All costs based on a criterion for noncarcinogenic PAH and heterocyclic PAH at the low end of the recommended range (4 micrograms per liter).

TABLE 6-14

SENSITIVITY OF PRESENT VALUE COSTS FOR

DRINKING WATER TREATMENT AND

NEW MT. SIMON-HINCKLEY WELLS TO

DIFFERENT EFFECTIVE INTEREST RATES[a]

(Revised 11/84)

Case	Total Present Value Cost[b] at Various Effective Annual Interest Rates, $ Millions		
	3 Percent	5 Percent	7 Percent
BEST CASE CONTAMINANT MIGRATION			
Drinking Water Treatment			
o GAC Treatment	3.6-13.3	2.6-8.8	1.8-6.4
o PAC or Ozone Injection	1.0-2.3	0.7-1.7	0.6-1.3
New Mt. Simon-Hinckley Wells	2.5-4.3	1.4-2.3	0.9-1.5
WORST CASE CONTAMINANT MIGRATION			
Drinking Water Treatment			
o GAC Treatment	4.6-16.7	2.9-10.4	2.2-7.7
o PAC or Ozone Injection	1.3-2.9	0.9-2.0	0.6-1.6
New Mt. Simon-Hinckley Wells	3.1-5.2	1.8-3.0	1.4-2.3

Notes:

(a) Excluding compliance monitoring costs, but including study costs for drinking water treatment.

[illegible] ration.

A firm conclusion may be drawn from the corrected tables. That conclusion is the same as drawn in the ERT report: that the cost of PAC/ozone drinking water treatment and alternate water supplies is comparable. Before this revision of the cost figures, the entire cost range for GAC water treatment exceeded the maximum projected cost for the other two alternatives (Table 6-13 of April 1983 report). The revised costs show that the most optimistic costs for GAC may be comparable to the most pessimistic costs for the new Mt. Simon-Hinckley wells. Overall, however, the cost of GAC still does not appear favorable compared to the PAC/ozone treatment alternatives.

2. A number of wells were omitted from the model. These include large municipal wells in Bloomington and Richfield.

The input data for the model were prepared from the information on well locations and pumpage rates given by Hult and Schoenberg (1981) and supplemented by information supplied by the Minnesota Department of Natural Resources (Memorandum from Gina Miller to Nancy Cichowicz, Dec. 1, 1982). The DNR information is a computer printout of municipal and industrial water use in Hennepin County by month in 1978 and 1979. Any pumping wells omitted from the ERT model reflect omissions in this data base, with few exceptions.

Important exceptions are the municipal wells in Bloomington. The pumpage rates for these wells are included in the DNR printout, however the wells were installed in 1973 and 1974. These wells were omitted from the calibration run which sought to duplicate the potentiometric surface in 1970, as reported by Norvitch et al. 1973. Figure E3-15 is also based upon the calibration run and thus does not include the influence of the Bloomington wells.

Since publication of ERT's report, new data on pumping wells have been made available by the USGS. New model inputs have been developed from these data and are shown here as Table 1. The importance of these data revisions were evaluated in model simulations reported in this memorandum.

TABLE 1

MAJOR GROUND-WATER PUMPAGE IN STUDY AREA

	Grid Location		Average Pumpage (cfs)	
	I	J	1970	1979
Mt. Simon-Hinckley Aquifer				
Edina 10	18	5	.95	.95
Richfield 7	23	6	0	.73
Edina 9	15	7	.31	.31
Edina 12	13	10	.76	.76
St. Louis Park 12	18	11	.67	.67
St. Louis Park 11	15	14	1.14	1.14
St. Louis Park 13	17	16	.25	.25
*	3	11	.70	.70
*	2	11	.60	.60
*	2	13	.60	.60
*	2	15	.50	.50
*	3	3	.60	.60
Grain 3-6	23	19	1.90	1.90
Prairie du Chien-Jordan Aquifer				
Bloomington	20	3	.19	.19
John Deere	22	3	.27	.27
Bloomington 1 & 2	19	4	0	5.70
Eden Prairie	9	5	0	.68
Edina 14	14	5	.20	.20
Edina 11	19	5	0	1.33
Edina 18	20	5	.21	.21
Edina 16	14	6	1.14	1.14
Airport	25	6	3.04	3.04
Dayton 1 & 3	20	6	.84	.84
Richfield 5 & 6	23	6	2.28	2.28

*Unidentified well(s). Data based on Guswa et al. (1982).

TABLE 1 (Continued)

MAJOR GROUND-WATER PUMPAGE IN STUDY AREA

	Grid Location		Average Pumpage (cfs)	
	I	J	1970	1979
Prairie du Chien-Jordan Aquifer (Continued)				
Richfield 1-4	23	7	3.23	3.23
Edina 6 & 17	18	7	1.05	1.05
Minnetonka 13	10	8	0	1.14
Excelsior	3	8	.49	.49
Edina 7	17	9	.19	.19
Minnetonka 15	6	9	0	.57
Edina 2	18	9	1.52	1.52
Minnetonka 11	8	10	1.14	1.14
Edina 13 & 15	15	10	1.14	1.14
Tonka Bay	3	10	.19	.19
St. Louis Park 14	16	11	.38	0
Hopkins	12	11	.76	0
St. Louis Park 6	17	12	.95	.95
Hopkins 3	14	12	.57	.57
Hopkins 4 & 5	11	13	1.52	1.52
Minnesota Rubber	17	13	.29	.29
St. Louis Park 5	14	14	.19	.19
St. Louis Park 4	18	13	.38	.38
Methodist Hospital	16	14	.67	.76
St. Louis Park 10 & 15	15	14	1.41	0
American Hardware	20	14	.19	.19
Minnetonka 6 & 7	11	14	0	.76
N.W. Hospital	23	14	.76	.76
McCourtney	15	15	.59	.30
St. Louis Park 7 & 9	15	15	.59	.30
Hiawatha	24	15	.57	.57
St. Louis Park 16	14	16	0	1.71

TABLE 1 (Continued)

MAJOR GROUND-WATER PUMPAGE IN STUDY AREA

	Grid Location		Average Pumpage (cfs)	
	I	J	1970	1979
Prairie du Chien-Jordan Aquifer (Continued)				
Prudential Insurance	20	16	.19	.19
St. Louis Park 8	13	16	.95	1.14
*	23	17	6.11	6.11
Champion	25	17	.38	.38
Northstar	24	17	1.65	1.65
General Mills	14	17	1.36	1.36
Wayzata	5	17	.38	.38
City Milk	22	17	.38	.38
*	23	18	3.00	2.43
Pillsbury	24	18	.19	.19
Long Lake	4	18	.19	.19
B.F. Nelson	24	19	.61	0
General Mills	14	19	1.14	1.14
Honeywell	25	19	1.51	1.51
Plymouth	9	19	.41	0
Honeywell	17	19	1.33	1.33
Fleischman	23	19	2.09	.57
Plymouth	8	19	0	3.04
Robbinsdale	18	20	1.14	1.14
St. Anthony	25	20	1.52	1.52
Robbinsdale 1 & 2	18	21	.76	.76
Sheily Rock	11	2	7.60	7.60
*	5	18	.75	.75
Minnetonka	7	15	.45	.45
W29	15	12	.05	.05
W80	12	12	.35	.35

TABLE 1 (Continued)

MAJOR GROUND-WATER PUMPAGE IN STUDY AREA

	Grid Location		Average Pumpage (cfs)	
	I	J	1970	1979
St. Peter Aquifer				
Edina	19	8	.08	.08
W45, W46	17	12	.01	.01
St. Louis Park 3	16	14	.15	.15
W62	15	15	.13	.13
Wolker 1	24	18	.13	.13
Bell 1 & 2	23	19	.21	.21
Robbinsdale 1	19	20	.19	.19
Drift Aquifer				
Dayton 4	20	6	.38	.38
Orono 2	2	13	0	.11
St. Louis Park 3	16	14	.27	.27
Metal, Inc.	24	19	1.14	1.14
Wayzata	3	17	.57	.57

3. The values for leakage coefficients between the Prairie du Chien-Jordan, Ironton-Galesville and Mt. Simon-Hinckley aquifers were questioned. It was also stated that the potentiometric heads in the Ironton-Galesville were apparently in error.

We pointed out at the meeting with the MPCA in August 1983 that we did not calibrate the model for the Ironton-Galesville, since there were no data against which to calibrate. The heads in the Ironton-Galesville were included in Table E2-3 by mistake, since the computed heads are meaningless in the absence of calibration.

At the meeting, we addressed the importance of the leakage coefficients. The essence of that discussion is that the leakage coefficients in the individual confining beds between the Prairie du Chien-Jordan and Mt. Simon-Hinckley layers are irrelevant, so long as the net leakage and head difference are correct.

The following is a more thorough explanation of this discussion. The rate of vertical leakage through a confining bed is given as:

$$\frac{Q}{A} = \frac{K_z}{m} \Delta h$$

where
- Q is the rate of flow,
- A is the horizontal area of flow,
- K_z is the vertical hydraulic conductivity,
- m is the confining bed thickness, and
- Δh is the head difference across the confining bed.

In travel vertically from the Prairie du Chien-Jordan to the Mt. Simon-Hinckley, water passes through the St. Lawrence-Franconia confining bed, the Ironton-Galesville aquifer and the Eau Claire confining bed. The vertical flow can be presumed to be approximately equal through each of these three layers:

$$\left(\frac{Q}{A}\right)_1 \simeq \left(\frac{Q}{A}\right)_2 \simeq \left(\frac{Q}{A}\right)_3 \simeq \frac{Q}{A}$$

The total head loss is the sum of the head loss through each of the three layers:

$$\Delta h = \Delta h_1 + \Delta h_2 + \Delta h_3$$

and, the total head loss can be shown to be mathematically related to the flow rate as:

$$\frac{Q}{A} = \left[\frac{1}{\left(\frac{m}{K}\right)_1 + \left(\frac{m}{K}\right)_2 + \left(\frac{m}{K}\right)_3} \right] \Delta h$$

Thus, the effective $\frac{K}{m}$ for all three layers is the quantity in brackets.

The values of the terms in the effective leakage are:

$\left(\frac{K}{m}\right)_1 = 7 \times 10^{-11}$ for the St. Lawrence-Franconia (as used in the ERT model)

$\left(\frac{K}{m}\right)_2 = 4.2 \times 10^{-8}$ for the Ironton-Galesville (based on information in Norvitch et al. 1973)

$\left(\frac{K}{m}\right)_3 = 1 \times 10^{-12}$ for the Eau Claire (as used in the ERT model)

The effective leakage reflects the leakage through the least leaky layer, the Eau Claire. The effective leakage value in the ERT model is:

$$\frac{K}{m} = 1 \times 10^{-12}$$

For the same travel path, the Prairie du Chien-Jordan to the Mt. Simon-Hinckley, Norvitch et al. 1973 give an effective leakage of:

$$\frac{K}{m} = 5.7 \times 10^{-12}$$

which differs by a factor of 5.7 from that in the ERT model. This is an acceptable difference given the uncertainties in the data.

Using the values employed by Guswa et al. (1982) (1.2×10^{-10} for the St. Lawrence-Franconia and 2.3×10^{-10} for the Eau Claire) the value of the leakage factor is:

$$\frac{K}{m} = 78 \times 10^{-12}$$

However, Guswa et al. (pg. 38) note that the values used for leakage in the Eau Claire and St. Lawrence-Franconia may be too high since the head in the Mt. Simon-Hinckley is predicted too low.

In work performed subsequent to the April 1983 report, the leakage coefficients were revised to give more realistic (but still uncalibrated) results for the Ironton-Galesville. The revised leakage coefficients are 5.0×10^{-12} for both the Eau Claire and the St. Lawrence-Franconia confining beds. The effective Prairie du Chien-Jordan to Mt. Simon-Hinckley leakage factor is then 2.5×10^{-12}.

To summarize, we believe that the leakage factors employed by Guswa et al. (1982) are too high, a conclusion also reached by Guswa et al. The values employed in the two versions of the ERT model are reasonably consistent with Norvitch et al. (1973) and yield reasonable calibrations for head in the Mt. Simon-Hinckley aquifer. The predicted head in the Ironton-Galesville aquifer is not relevant, so long as the head in the Mt. Simon-Hinckley is correct. Model results for the Ironton-Galesville are neither calibrated nor used to make predictions.

4. The rate of precipitation recharge is too high, based on a comparison with Guswa et al. (1982).

The rate of recharge used in the ERT model is 7.5 in/yr, a value determined by calibration. The value used by Guswa et al. (1982) is 3.5 in/yr.

A part of the difference between these two values is explained by the difference in the area modeled. Norvitch et al. (1973) indicate that precipitation recharge is greater in the Twin Cities Metropolitan Area than in the wider area they consider (approximately two times the area of the seven-county metropolitan area). Norvitch et al. define the rate of precipitation recharge to be 4.23 in/yr for the wider area, and 5.24 in/yr for the Twin Cities Metropolitan Area. This latter area corresponds with Guswa's modeling area. Larson-Higdem et al. (1975) found a value of 5.6 in/yr gave the best results for the rate of recharge to the Prairie du Chien-Jordan aquifer in the Twin Cities Metropolitan Area.

It is our opinion that the recharge value employed by Guswa et al. is probably too low. Guswa et al. indicate that the recharge rate is a parameter they will review in the development of their final model version. The version published in 1982 is a preliminary version.

Nevertheless, the value of precipitation used in the ERT model appears to be high. Subsequent revisions of the model have enabled a more realistic value of precipitation (5.2 inches/year) to be used. Several model changes accompany this parameter change, however. Boundary conditions are treated significantly differently in the revised model using model capabilities added by Torak (1982). These modified boundary conditions change the interaction between the aquifer and Lakes Minnetonka, Calhoun, Harriet, Bush, Anderson and Medicine, and between the aquifer and the Minnesota and Mississippi Rivers. Another change allowing a lesser precipitation rate is an adjustment of leakage factors between model layers 5 and 4 in the southern area of the model where the St. Peter aquifer is absent. The net effect of the changes to model boundary conditions and leakage factors is a more realistic treatment of the drift aquifer, enabling a reduction in the rate of precipitation. Nonetheless, the net effect on predicted rates and direction of ground-water flow are relatively minor (see figures for R1 simulation).

5. There is a four-mile "glitch" in the model-field data comparison for the Prairie du Chien-Jordan calibration (Figure E2-14). The discrepancy occurs in the 800 foot contour line east of the Reilly site.

The location of the loop in the 800 foot contour was apparently a concern of the PCA in the calibration results. In fact, the loop migrates from summer to winter. The model results are closer to the winter location than the summer. The field data shown in Figure E2-14 are the summer configuration while the computer run is based on annual average conditions. Thus, the discrepancy is not as great as it seems.

The location of the loop migrates over other time periods as well. The summer potentiometric surface contours shown by Norvitch et al. (1973, Figure 43) show the 800 foot contour as two closed depressions rather than as a loop in the contour line. The difference is simply one of interpretation, however. Were Norvitch's data drawn as a loop, the loop would be east and possibly south of that in Figure E2-14 which is based on Hult and Schoenberg (1981). In Norvitch's Figure 20, the loop disappears altogether in the winter potentiometric contour.

In general, we stand by our assessment that the model is reasonably calibrated. The model duplicates the existence of a depression in the potentiometric surface beneath St. Louis Park and locates it in fair agreement with the available data. The extent of this agreement is consistent with the real movement of the contour line over the year and with the uncertainty and interpretation that is implicit in the various contour maps. Some sense of the uncertainty in calibration contours may be gained by close inspection of the actual water level measurements indicated in Figure 10 of Hult and Schoenberg (1981). For example, wells with measured potentials of 796 and 800 feet are well to the west of the drawn 800 foot contour line.

6. The divide in Figure E3-15 is based on 1976 pumping rates. With well closures will the divide disappear? Is the divide intact with the present well closures?

Computer simulations show that the divide remains intact with the present well closures. The divide location migrates to the south in the St. Louis Park area, as wells within the divide close. After closure of SLP6 and E2 (both are major wells) the divide weakens considerably and continued transport to the south is predicted (see figures for R3, R4, or R5). Further discussion of the predicted divide is included below.

7. Does the ERT modeling study address the long-term potential yield of the Mt. Simon-Hinckley aquifer?

This issue is addressed in Section E3.5.2 of the ERT report. The report describes the model use in this way as a heuristic test. It is heuristic in the sense that the model was not designed to simulate the long-term yield of the Mt. Simon-Hinckley and does so only approximately. As a result, the computer model is limited in the accuracy with which it can make predictions for the Mt. Simon-Hinckley aquifer. The nature of the Mt. Simon-Hinckley in the St. Louis Park area is such that water that is pumped from wells must be replenished by water that flows laterally from outlying parts of the aquifer; vertical recharge from overlying aquifers is negligible. Because flow to wells must be fed by the neighboring parts of the aquifer, the areal extent of the model is critical. The model as presently constructed covers a relatively small area of the Mt. Simon-Hinckley. This is adequate for the main purpose of the model: to analyze flow patterns under present conditions. However, it becomes less accurate as it is used to evaluate increased rates of future pumping from the aquifer. Any errors will be conservative in the sense that the yield of the aquifer is underpredicted. Stated another way, the predicted drawdown due to increased pumping will be greater than actual. Thus, the model unfairly represents the adequacy of the Mt. Simon-Hinckley to sustain increased withdrawals.

8. The western boundary of the model is inaccurate for the Prairie du Chien-Jordan. It fails to account for flow from Lake Minnetonka.

The western boundary of the model was selected to correspond with the western extent of the Prairie du Chien-Jordan. The correspondence is approximate but reasonably accurate.

The influence of Lake Minnetonka is accounted for in the model as originally constructed. Lake Minnetonka is a constant head boundary condition in the model which recharges the drift and Prairie du Chien subcrop. The western model boundary passes through Lake Minnetonka in an area of essentially flat gradients in the water table as shown in Larson-Higdem et al. (1975) . Thus, lateral drift transport is small to none across the model boundary.

There may be some lateral transport from the drift aquifer to the Prairie du Chien that is not accounted for in the model. In general, it is considered conservative modeling practice to place boundaries sufficiently far from the area of interest that boundary fluxes will not significantly influence the model predictions of interest. This philosophy was adhered to in the ERT model. We believe that any changes to the western boundary would be too slight to affect the nature of the model predictions in the St. Louis Park area. That is, there are no physically realistic reformulations of the model boundary conditions that would alter the existence of the ground-water divide and the general direction of ground-water transport. This is confirmed by the model modifications discussed below.

USGS Model Revisions

Several important changes were made to the original ground-water model of St. Louis Park, MN utilizing improvements in the USGS three-dimensinal flow model computer program. The five aquifers beneath the site are bordered by two large rivers and penetrated by several large lakes. The revisions to the USGS model by Torak (1982) enable rivers and lakes to be modeled more realistically as leaky boundaries rather than constant head boundaries.

The Minnesota and Mississippi Rivers have been modeled as either head-dependent sources or drains for the Drift, the St. Peter, and the Prairie du Chien-Jordan aquifers. The rivers were set as head-dependent nodes for the St. Peter and the Prairie du Chien-Jordan aquifers since the rivers penetrate to these aquifers through the overlying drift. For the Drift aquifer, the rivers and lakes were modeled as drains since the hydraulic head in the aquifer is perpetually higher than the surface waters. Lakes were modeled as head-dependent nodes for the St. Peter and Prairie du Chien-Jordan aquifers. The lakes modeled were Minnetonka, Calhoun, Harriet, Bush, Anderson, and Medicine.

The resulting model was then calibrated to a new set of pumping well data. A USGS record of annual well withdrawals in the counties surrounding and including Minneapolis-St. Paul provided coherent data for the period 1970-79. The pumping data were divided into two halves, one for 1970-74 and the other for 1975-79 (see Table 1). This division enabled comparison of the water table and ground-water flow paths before and after shutdown of contaminated wells in St. Louis Park as well as reflecting some of the changing demands on the aquifers as ground-water utilization increased. The model was calibrated to the pumping data of 1970-74 since the best available water table data for all of the aquifers is that for 1970-1971 in Norvitch et al. (1973).

Adjustment of the leakage coefficient between model layer 5 and model layer 4 was an important step in recalibrating the model. In the southern portion of the modeled area, the Drift aquifer overlies the Prairie du Chien-Jordan aquifer with the St. Peter Sandstone absent. Therefore the leakage coefficient between model layer 5 and model layer 4 was set to a value for the silt and clay till, 3.47×10^{-7} ft/sec. (Norvitch et al. 1973, p. 110).

A second significant change to the model is in the specified rate of precipitation recharge. The annual recharge rate has been lowered to 5.2 inches/year, which agrees with Norvitch's value for the Twin Cities area (Norvitch et al. 1973, pg. 167). Some additional recharge is introduced in the northwestern portion of the model through constant head nodes placed along the model's western boundary (column

2, all rows) and a portion of the northern boundary (row 21, columns 3 through 8). The net increase in total recharge flow due to these additional constant head nodes is 8.1 cfs. The total recharge flow due to 5.2 inches/year distributed over the entire model area is 211 cfs, thus the added inflow is relatively small (see attached Figures 1 through 4 for hydraulic head in each model layer).

Using the revised USGS ground-water flow model, a number of key points in the original April 1983 report were rechecked to see if any significant differences exist between the old model and the updated one. The items of interest are all contained in Appendix E of the report and deal mainly with numerical predictions (i.e., velocities, time of travel, flow balance). The model comparisons, described in detail below, show that no significant differences exist between the present model results and the original model results.

Beginning with the Drift-Plateville aquifer in the revised model, the flow in the drift aquifer is to the east and south at approximately 0.5 ft/day. The predicted travel time to the buried bedrock valley (Prairie du Chien contact) is 60-70 years. Figure E3-3 in the April 1983 report depicts the relative magnitude of horizontal and vertical flow around the buried bedrock valley. The updated model confirms the differing order of magnitude between horizontal and vertical flow (horizontal flow is roughly two orders of magnitude greater than vertical flow in the Drift). Vertical and horizontal flow velocities are both diminished slightly in the updated model due to the lower and more realistic precipitation rate.

In the St. Peter aquifer enhanced leakage occurs in the revised model at the buried bedrock valley where the basal St. Peter confining bed is absent. The vertical flow rate is 1×10^{-3} cfs which is roughly 1.5 times the average value. The horizontal flow in the St. Peter is an average of 0.1 to 0.2 ft/day to the southeast. This results in a travel time from the Reilly site to the buried bedrock valley of 50 years, in agreement with the original findings. The valley continues to act as a "hydraulic barrier" diverting flow north of the site to the northeast and flow south of the site to the southeast.

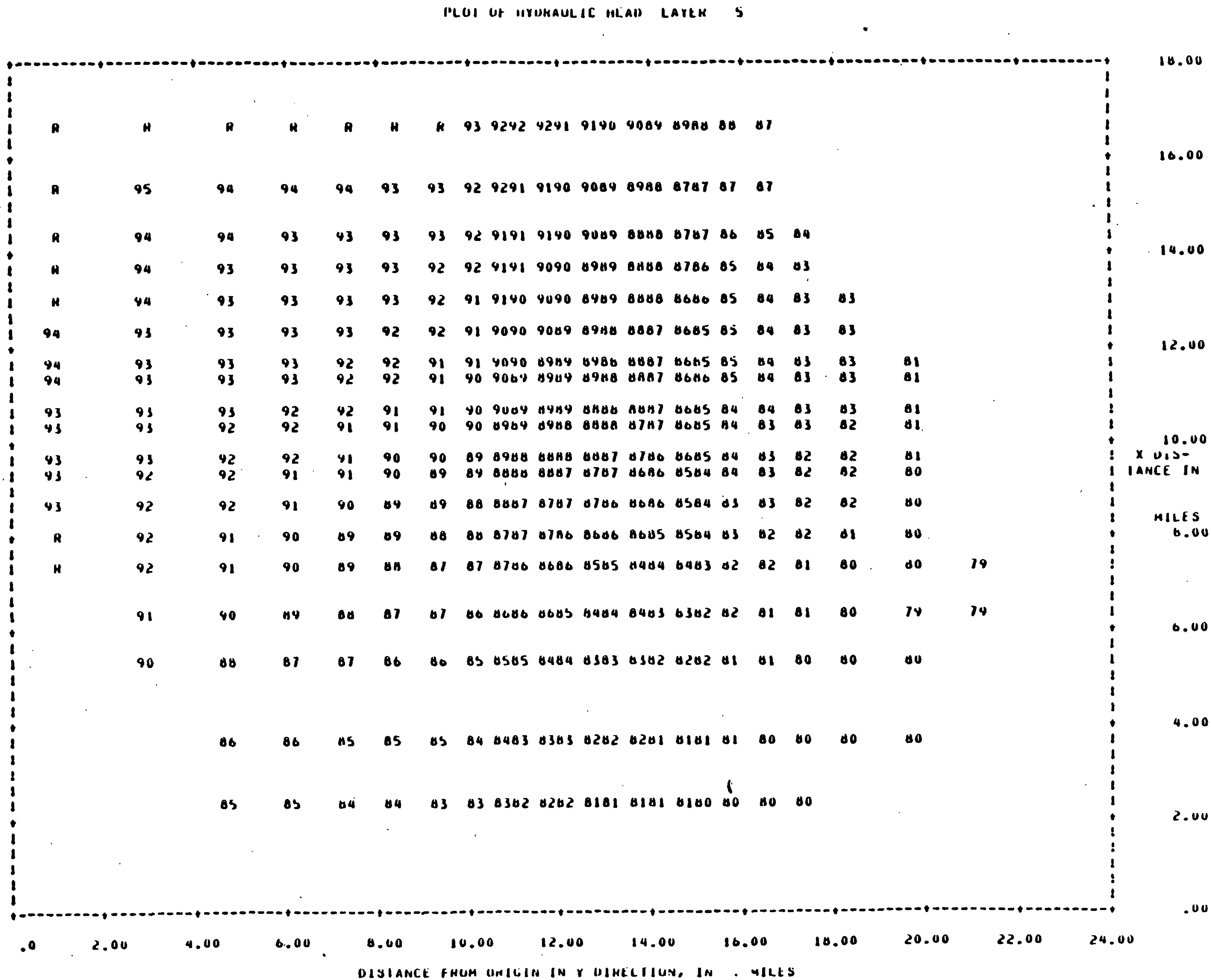

Figure 1 Calibrated Hydraulic Head in Model Layer 5 (Drift-Platteville Aquifer)

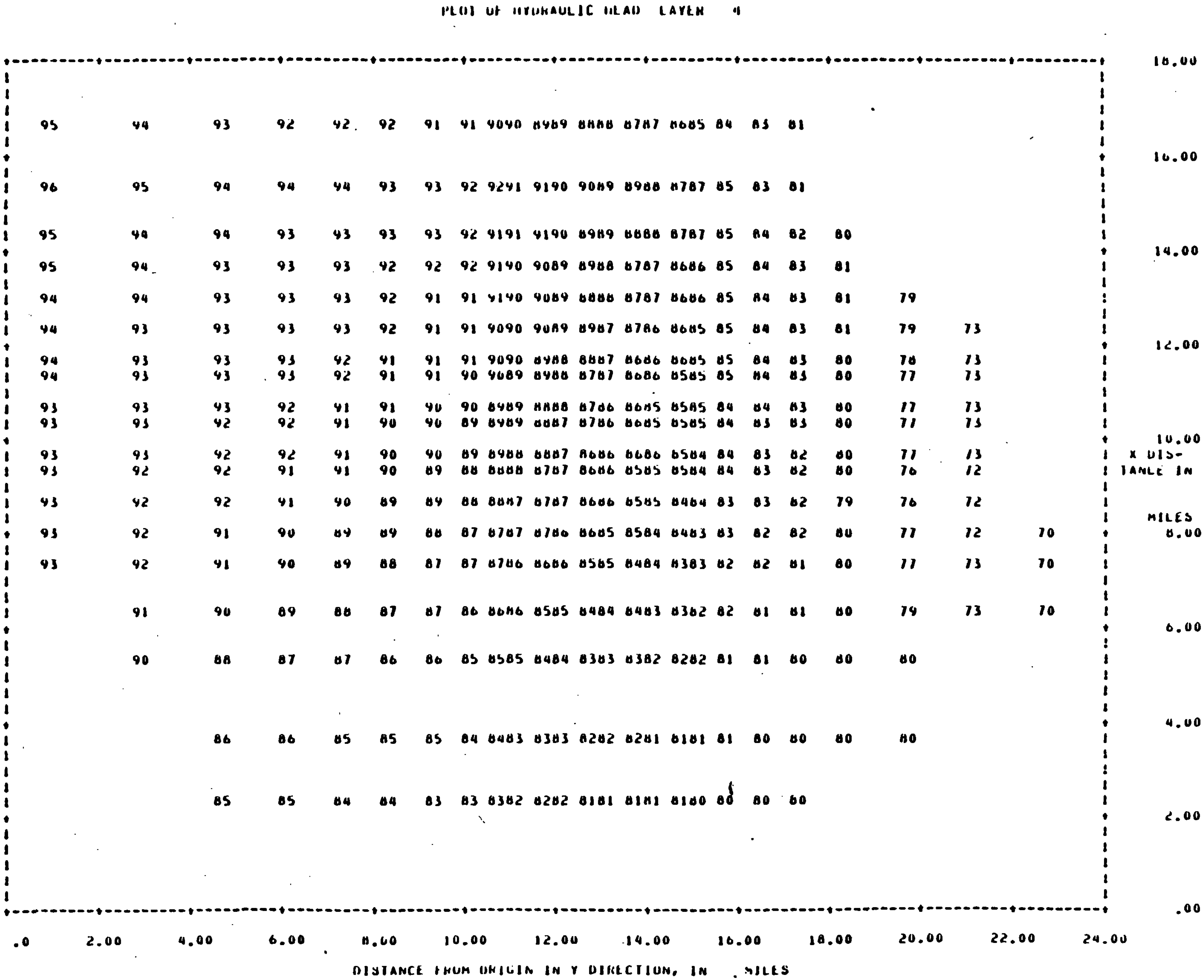

Figure 2 Calibrated Hydraulic Head in Model Layer 4 (St. Peter Aquifer)

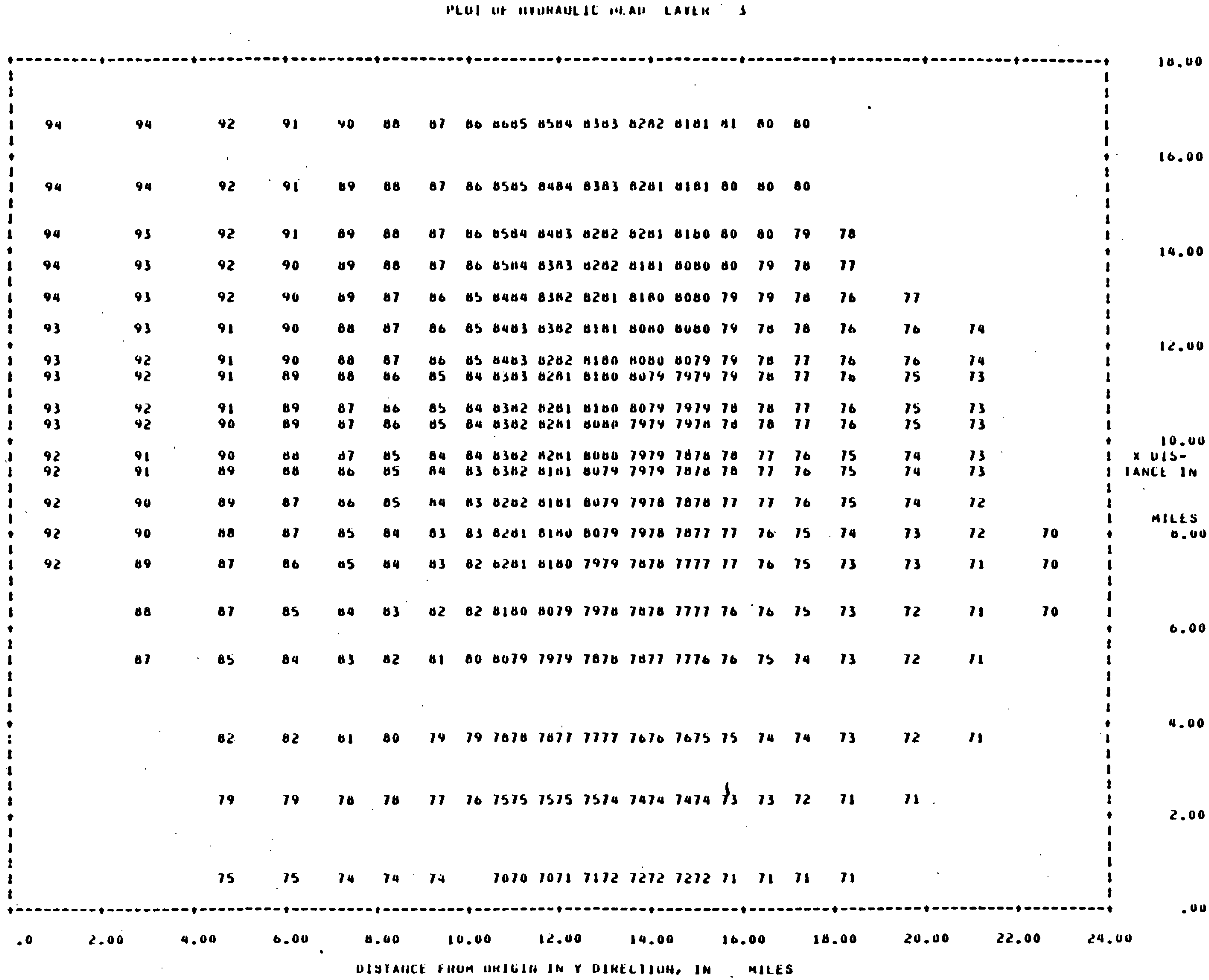

Figure 3 Calibrated Hydraulic Head in Model Layer 3 (Prairie du Chien-Jordan Aquifer)

PLOT OF HYDRAULIC HEAD LAYER 1

R	R	81	78	76	74	73	71	7069	6867	66 R	R R	R R	R	R	R	R	R	R	R
R	84	81	78	76	74	72	71	7069	6867	6666	6565	6464	64	63	63	62	64	66	68
R	84	81	78	76	74	72	71	6969	6867	6665	6564	6464	63	62	61	57	63	66	67
R	83	80	78	75	73	72	70	6968	6766	6565	6464	6363	63	62	62	61	63	65	67
R	83	80	77	75	73	71	70	6968	6665	6464	6363	6363	62	62	62	62	63	65	67
R	83	80	77	75	73	71	70	6867	6665	6362	6261	6262	62	62	62	63	64	65	67
R	82	79	77	75	73	71	69	6867	6564	6261	6161	6162	62	62	63	63	64	65	67
R	82	79	77	75	73	71	69	6866	6563	6158	6061	6162	62	62	63	63	64	65	66
R	81	79	77	74	72	71	69	6766	6563	6260	6061	6161	62	62	63	63	64	65	66
R	81	79	76	74	72	71	69	6766	6463	6261	6161	6061	62	62	63	64	64	65	66
R	80	79	76	74	72	70	69	6766	6462	6261	6160	5961	62	63	63	64	64	65	66
R	80	78	76	74	72	70	69	6766	6461	6262	6161	6161	62	63	63	64	64	65	65
R	81	78	76	74	72	70	69	6766	6463	6262	6262	6262	62	63	63	64	64	65	65
R	81	78	76	74	72	70	69	6766	6564	6363	6262	6262	63	63	64	64	65	65	65
R	81	78	76	74	72	71	69	6867	6665	6463	6363	6363	63	63	64	64	65	65	65
R	81	78	76	74	72	71	69	6867	6666	6564	6363	6363	63	64	64	64	65	65	65
R	80	78	76	74	72	71	70	6968	6766	6665	6463	6162	63	64	64	65	65	65	65
R	79	77	75	74	72	71	70	6969	6867	6766	6665	6565	65	65	65	65	65	65	65
R	77	76	75	74	72	71	70	7069	6968	6867	6766	6666	66	65	65	65	65	65	65
R	78	76	75	73	72	71	71	7069	6968	6868	6767	6766	66	66	66	66	65	65	65

X DISTANCE IN MILES: 18.00, 16.00, 14.00, 12.00, 10.00, 8.00, 6.00, 4.00, 2.00, .00

.0 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00 22.00 24.00

DISTANCE FROM ORIGIN IN Y DIRECTION, IN MILES

Figure 4 Calibrated Hydraulic Head in Model Layer 1 (Mt. Simon-Hinckley Aquifer)

The results of the updated model confirm the original finding of a pronounced ground-water divide in the Prairie du Chien-Jordan aquifer, south and east of the site when all wells are pumping. With the present well closures the divide is weakened. The increase in pumpage at SLP6 has ensured the continued existence of a divide but has put that well in jeopardy of contamination (see Figure 15). The predicted travel-time for flow from the Reilly site to reach SLP6 is 25 years in the updated version as compared to 65 years in the original report. This is due to a change in K and n values to the more conservative numbers for the Prairie du Chien Group. The additional time for flow to reach E2 after SLP6 is shut off is 15 years. Flow in the Prairie du Chien-Jordan aquifer has not changed significantly due to the model revisions largely because it receives "second-order" effects from the changes to the model. The end result between the original and the present simulations remains the same.

The changes to the model produced virtually no net effect on the flow in the Mt. Simon-Hinckley aquifer. This is because changes made can only produce "third-order" effects on the aquifer, meaning flow must pass through overlying aquifers first and the changes in relative head due to this are small.

Model Simulations

Six model scenarios were simulated using the updated version of the USGS model. The differences between each were the pumping data used for the simulation. The first two simulations, R1 and R2, used pumping data from 1970. Results from R1 appear in Figures 5 through 11. R1 utilized the pumping data presented in the original report in Appendix E. R1 confirmed the agreement between the original model and the updated one (Compare Figures 5 through 11 with corresponding figures in Appendix E of ERT 1983 report). R2 utilized yearly average pumping data supplied by the USGS (see Table 1) and included several large pumping wells in Bloomington and Richfield. The results of R2 (Figures 12 and 13) and R1 agree very well with the original findings in the April 1983 ERT report.

Figure 5 Simulation R1 Predicted Flow Pattern in Model Layer 5

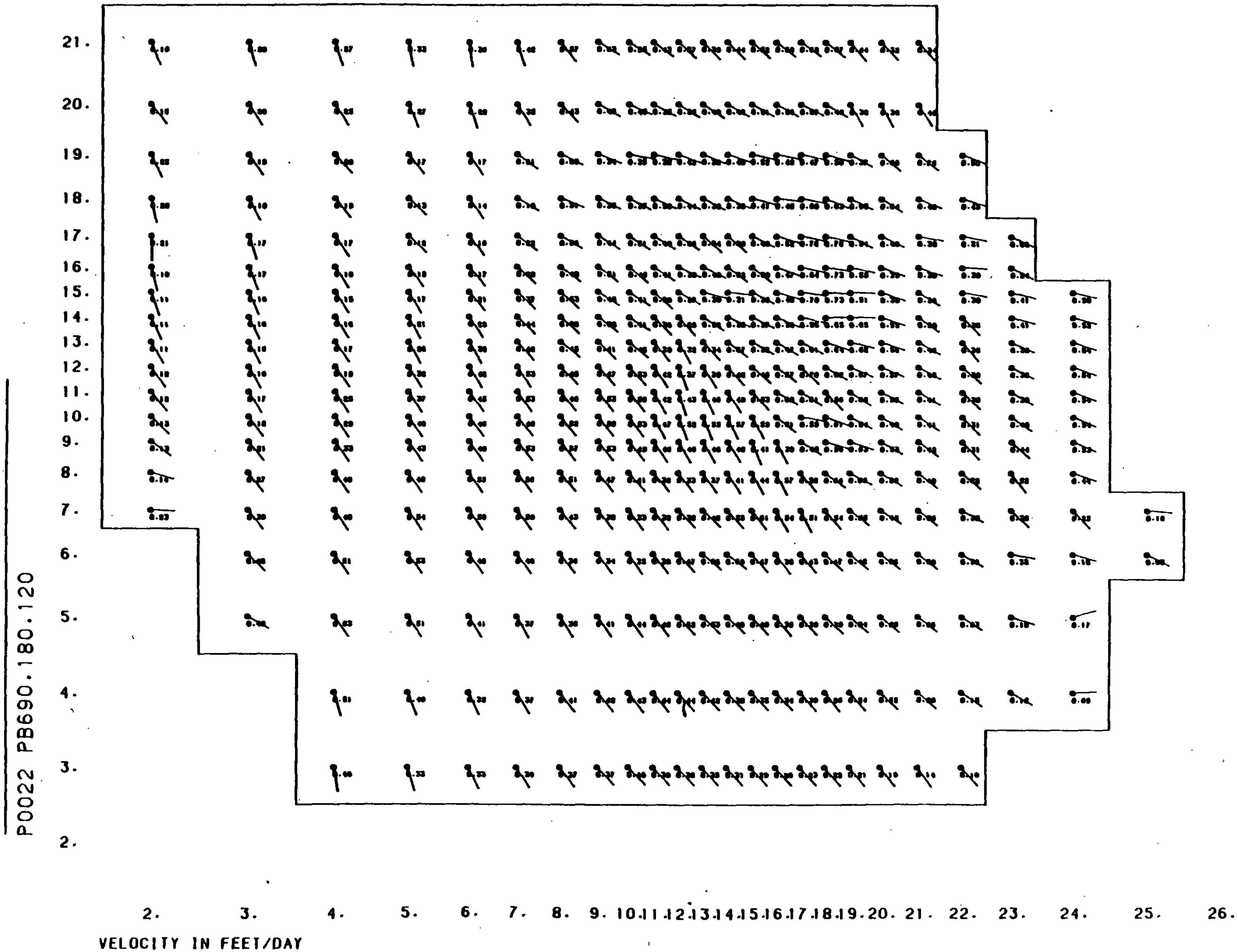

Figure 6 Simulation R1 Predicted Travel Paths in Model Layer 5

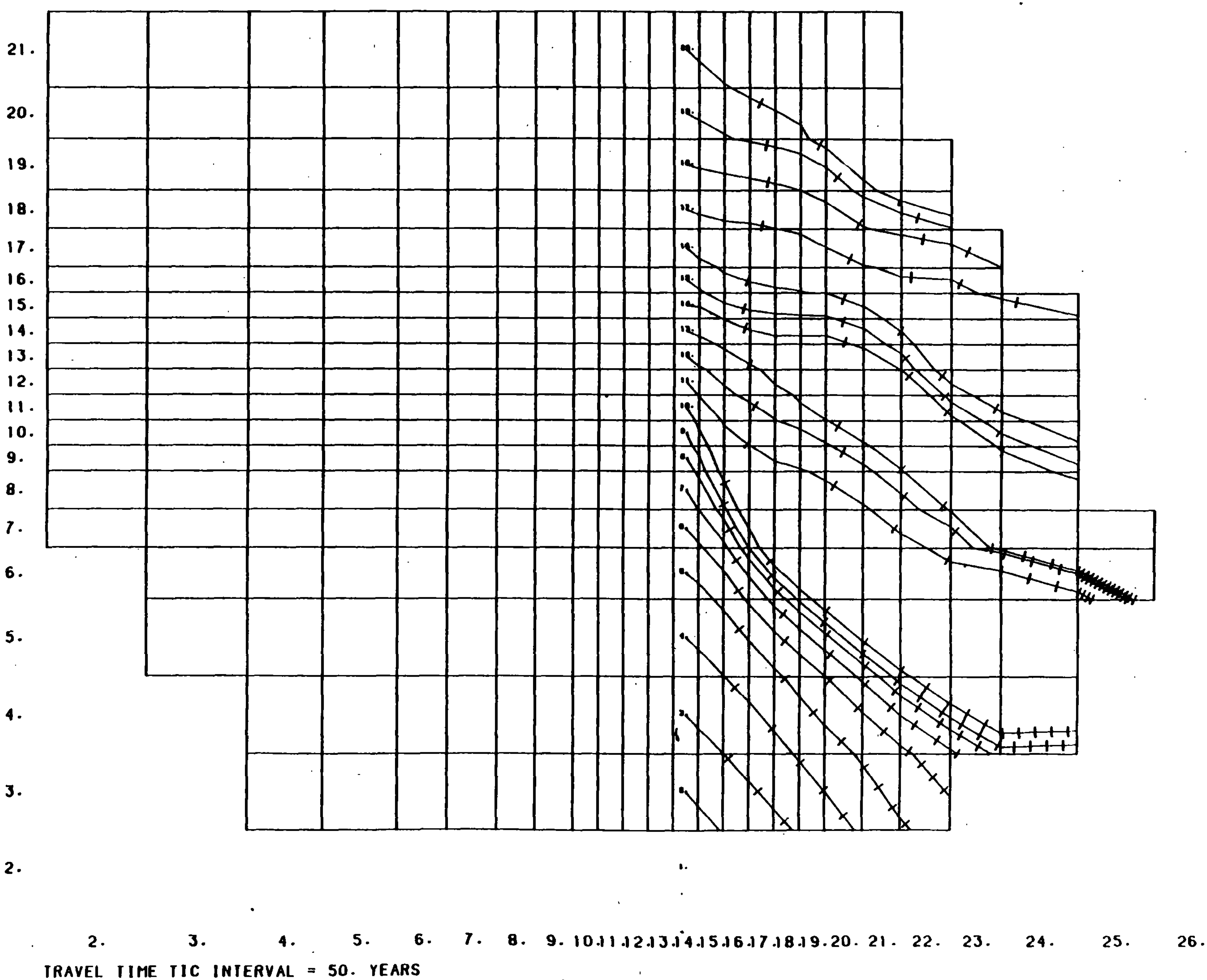

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Figure 7 Simulation R1 Predicted Flow Pattern in Model Layer 4

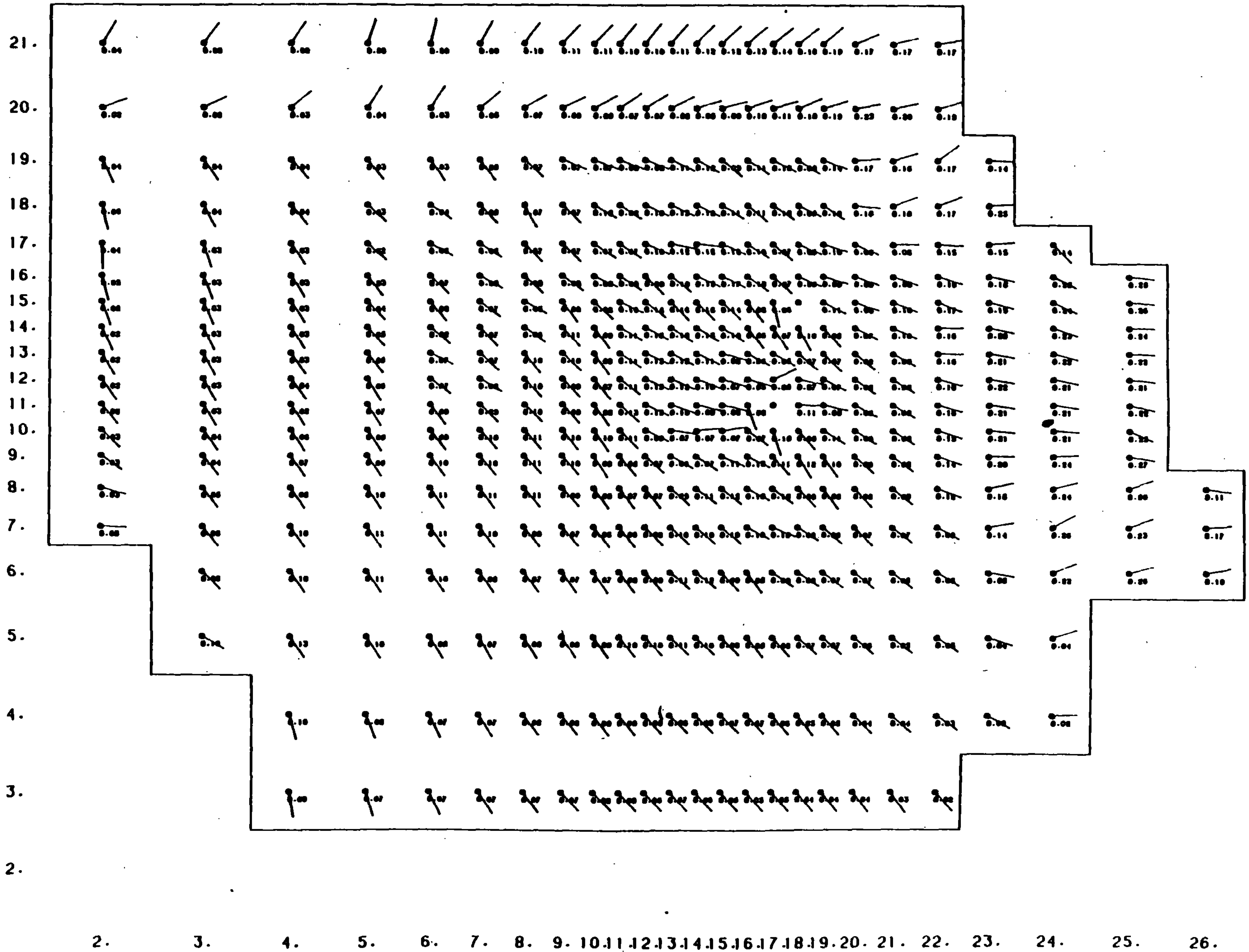
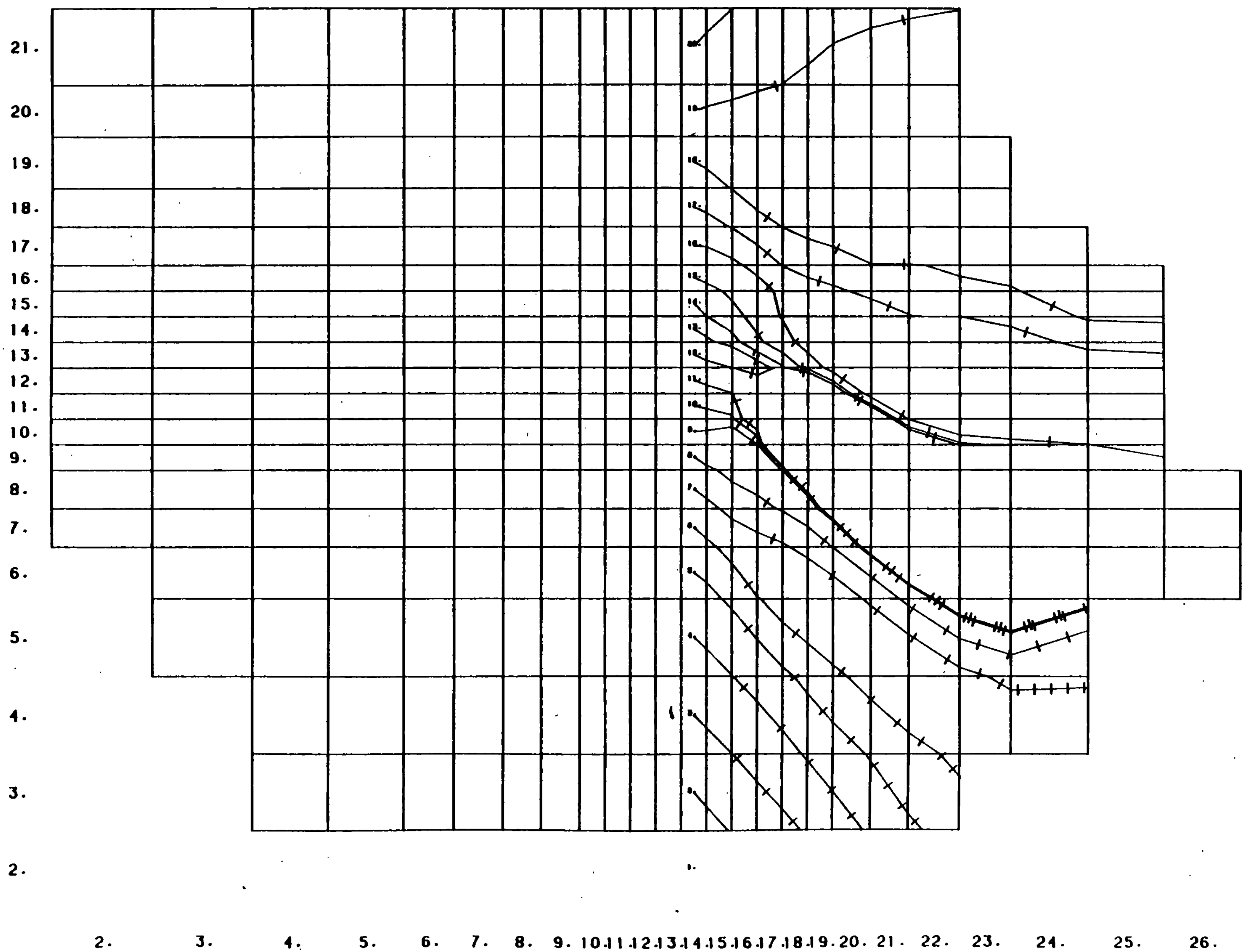


Figure 8 Simulation R1 Predicted Travel Paths in Model Layer 4



250. YEARS

Figure 9 Simulation R1 Predicted Flow Pattern in Model Layer 3

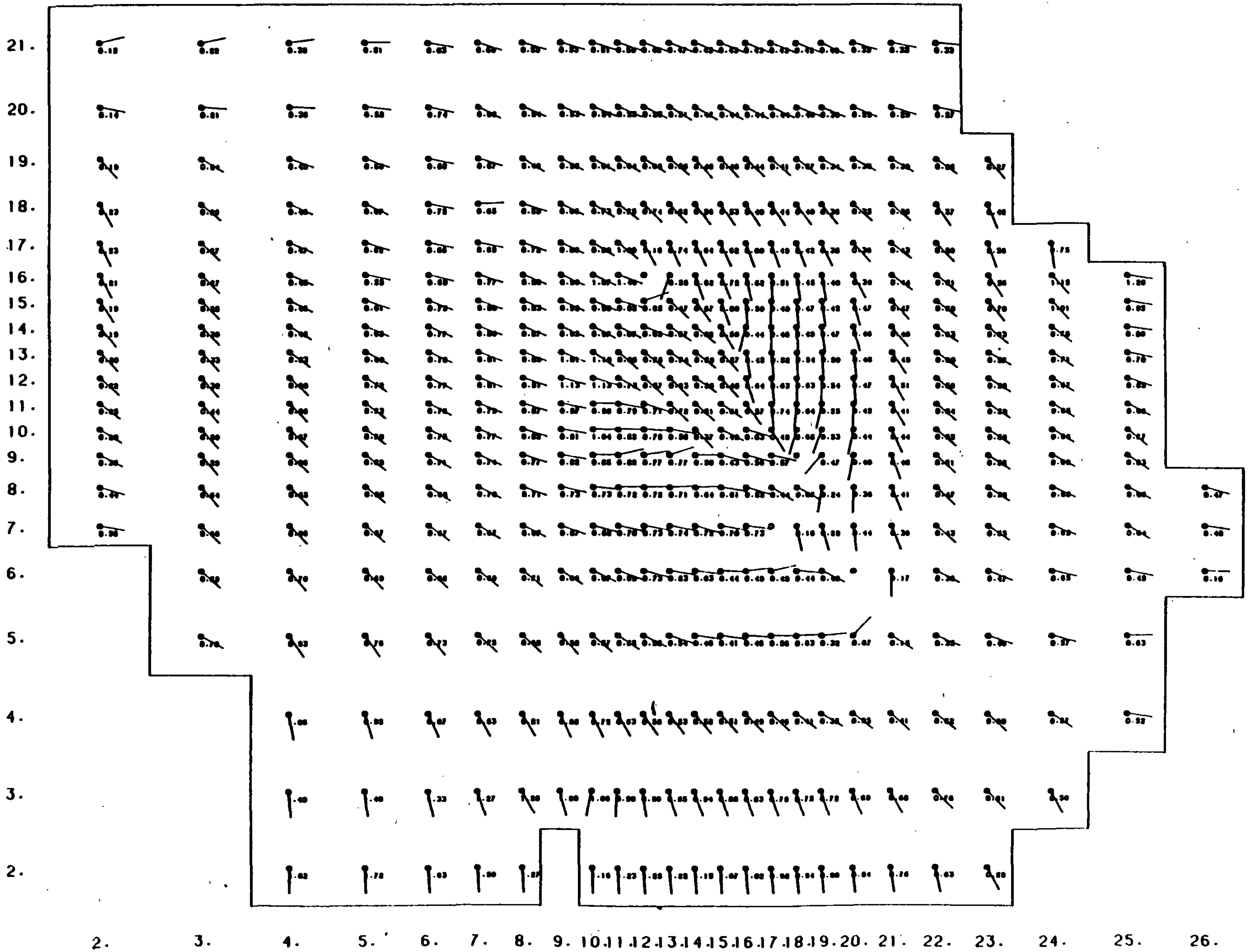
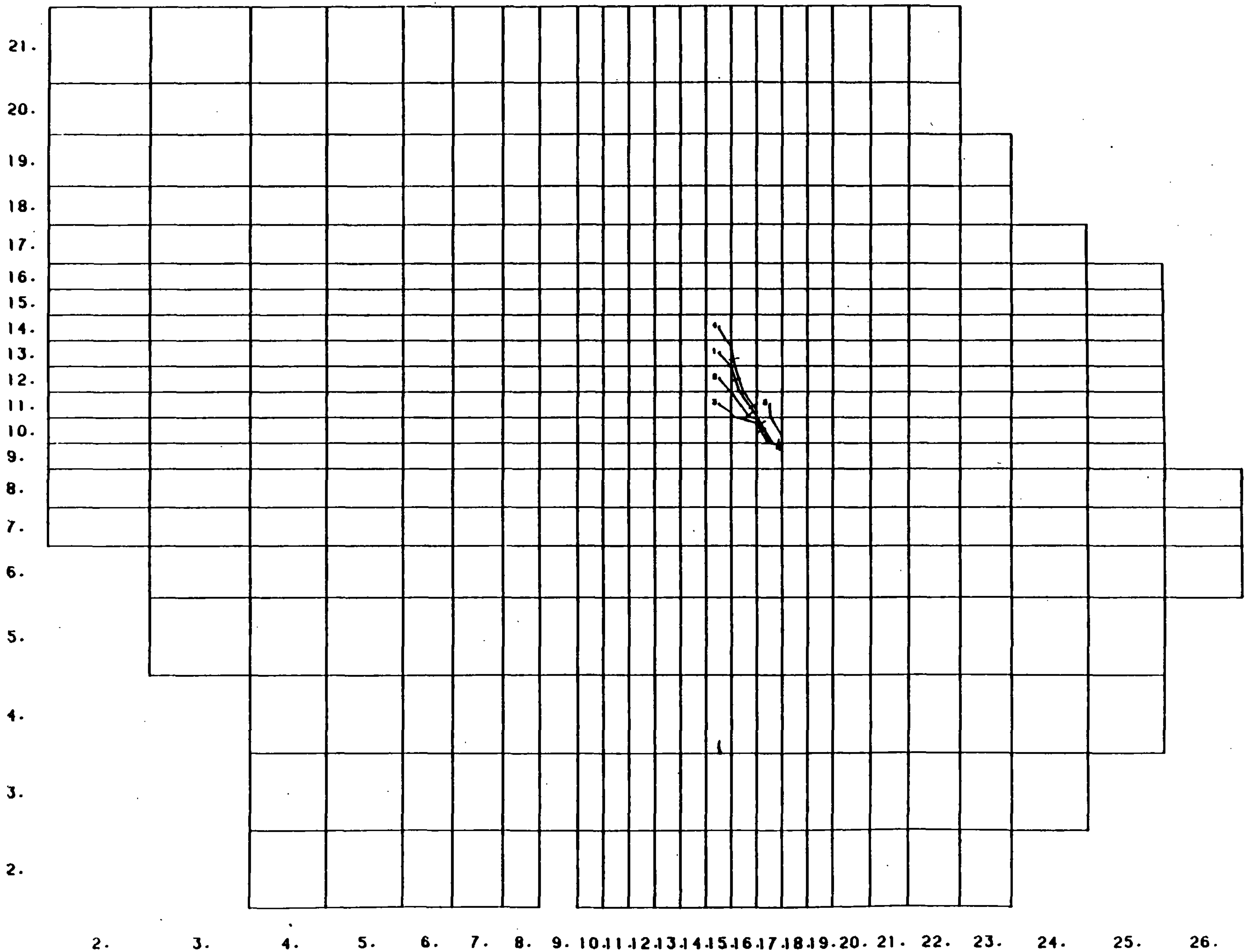


Figure 10 Simulation R1 Predicted Travel Paths in Model Layer 3



TRAVEL TIME TIC INTERVAL = 25. YEARS

P0019 PB690.180.120

Figure 11 Simulation R1 Predicted Flow Pattern in Model Layer 1

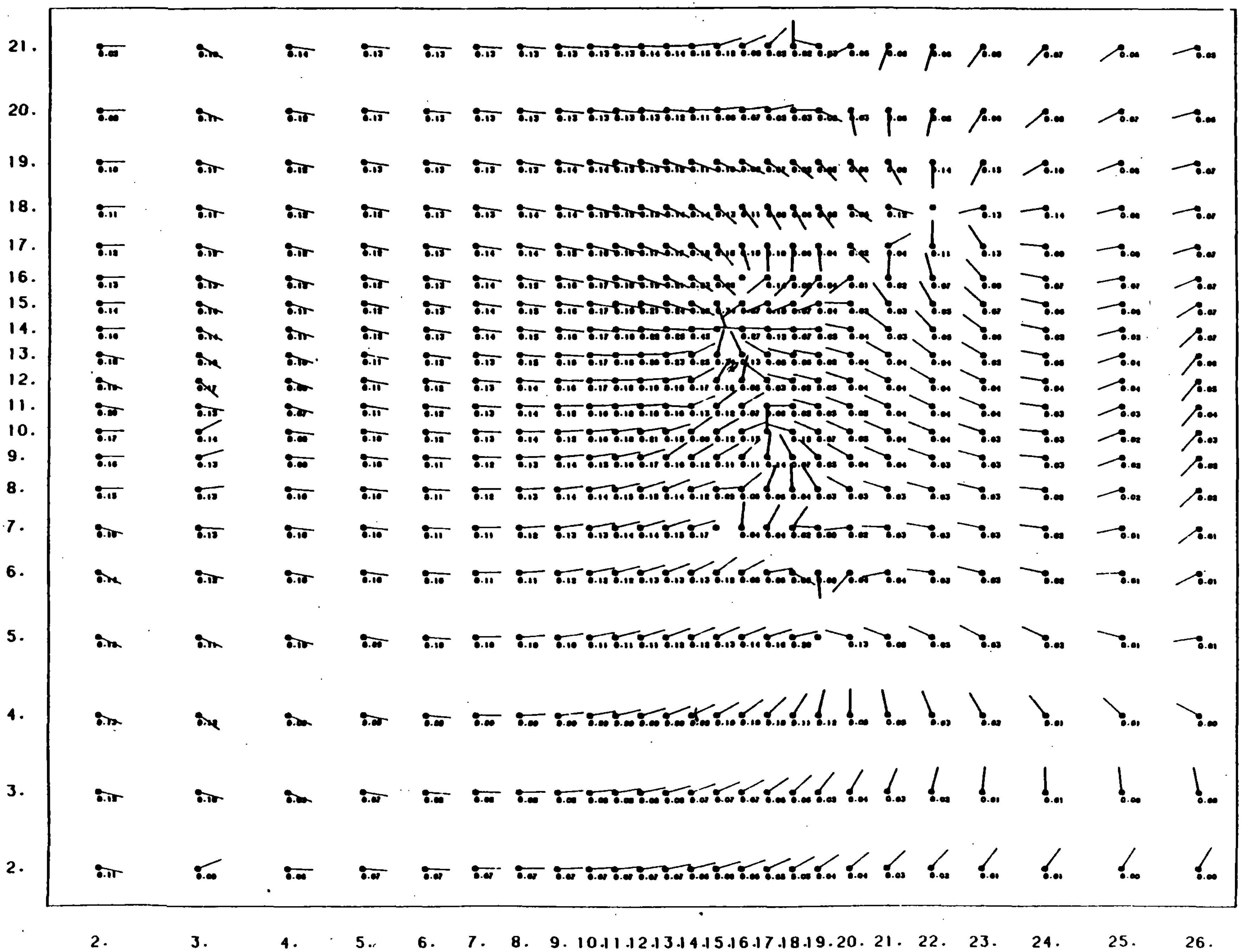


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Figure 12 Simulation R2 Predicted Flow Pattern in Model Layer 3

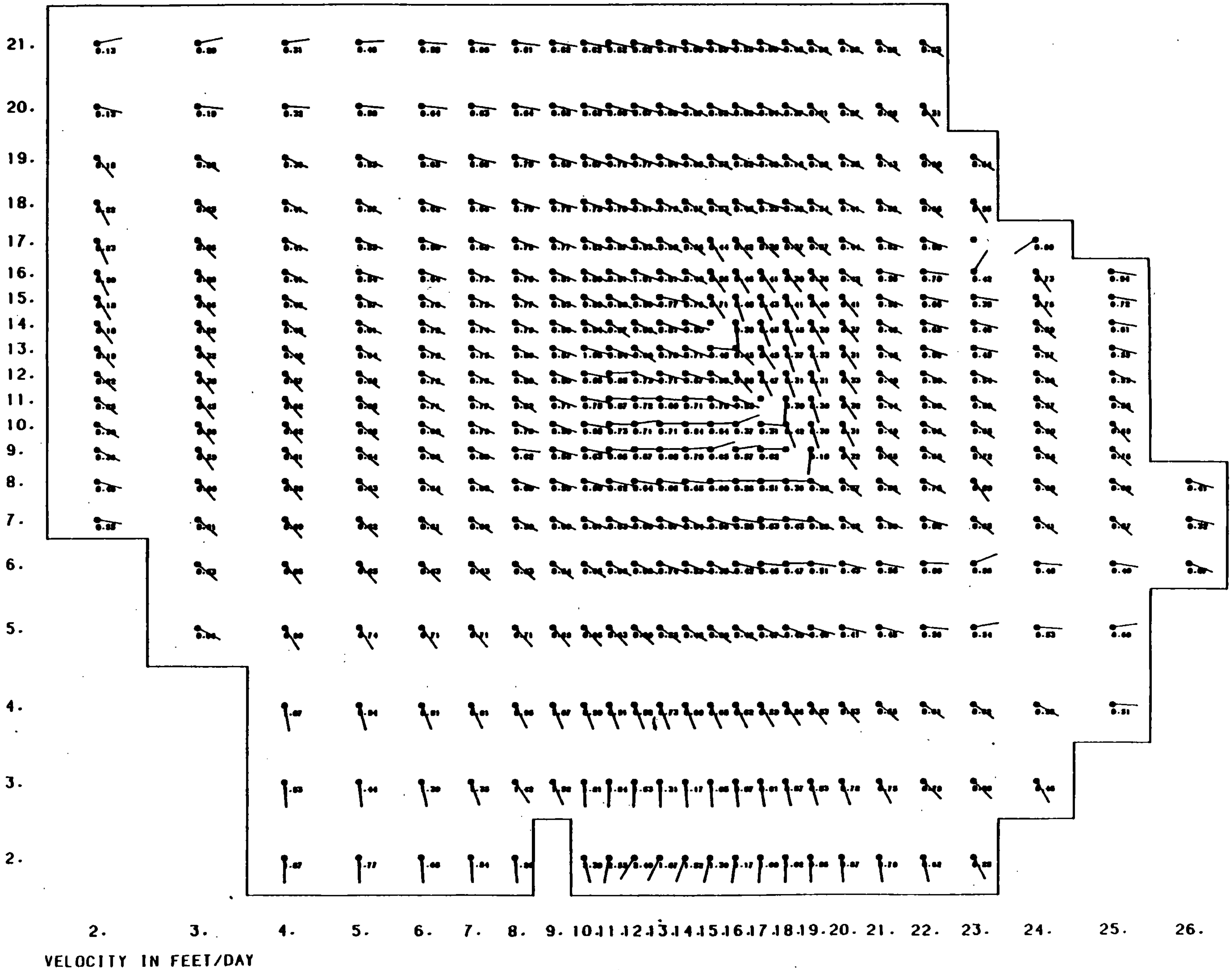
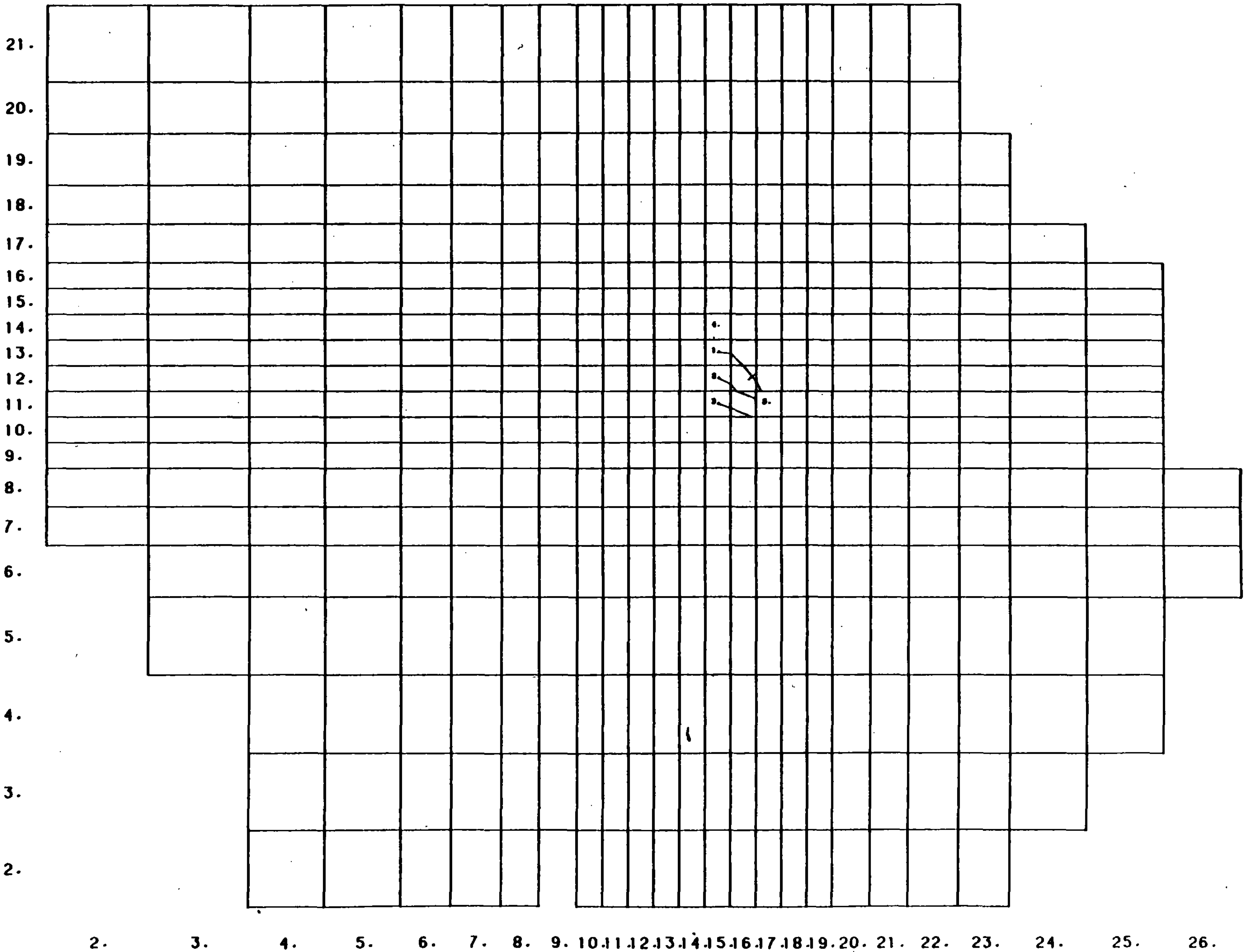


Figure 13 Simulation R2 Predicted Travel Paths in Model Layer 3



TRAVEL TIME TIC INTERVAL = 25. YEARS

Three simulations were performed with 1979 pumping data. R3 utilized the yearly average pumping rates from the USGS (see Table 1). The results of R3 (Figures 14 and 15) show the divide is severely weakened by the St. Louis Park well closures in 1978 and 1979, but that contaminant in the Prairie du Chien-Jordan would be captured by SLP6 or E2. If SLP6 is shut down, however, the divide disappears using the 1979 data with present well shutdowns included. (This simulation is not included with this report.) R4 represents the effects of the winter of 1979 pumping rates on the aquifers. The noteworthy result in R4 is that the divide in the Prairie du Chien-Jordan aquifer is gone due to low seasonal pumping rates and the prior well closures in 1978 and 1979 (Figures 16 and 17). R5 represents the summer of 1979 and shows the divide in the Prairie du Chien-Jordan intact (Figures 18 and 19).

The final simulation, R6, used the 1979 average data from the USGS with St. Louis Park wells 7, 9, 10, and 15 pumping at the rates suggested in the 1983 report. This data set was termed the 1989 case, to represent a future case for the aquifers beneath St. Louis Park. The increased pumpage of the Prairie du Chien-Jordan aquifer in R6 enhances the divide and shows local capture of contamination that is north of the site and continued capture of contaminant moving south and east of the site (Figures 20 and 21).

Figure 14 Simulation R3 Predicted Flow Pattern in Model Layer 3

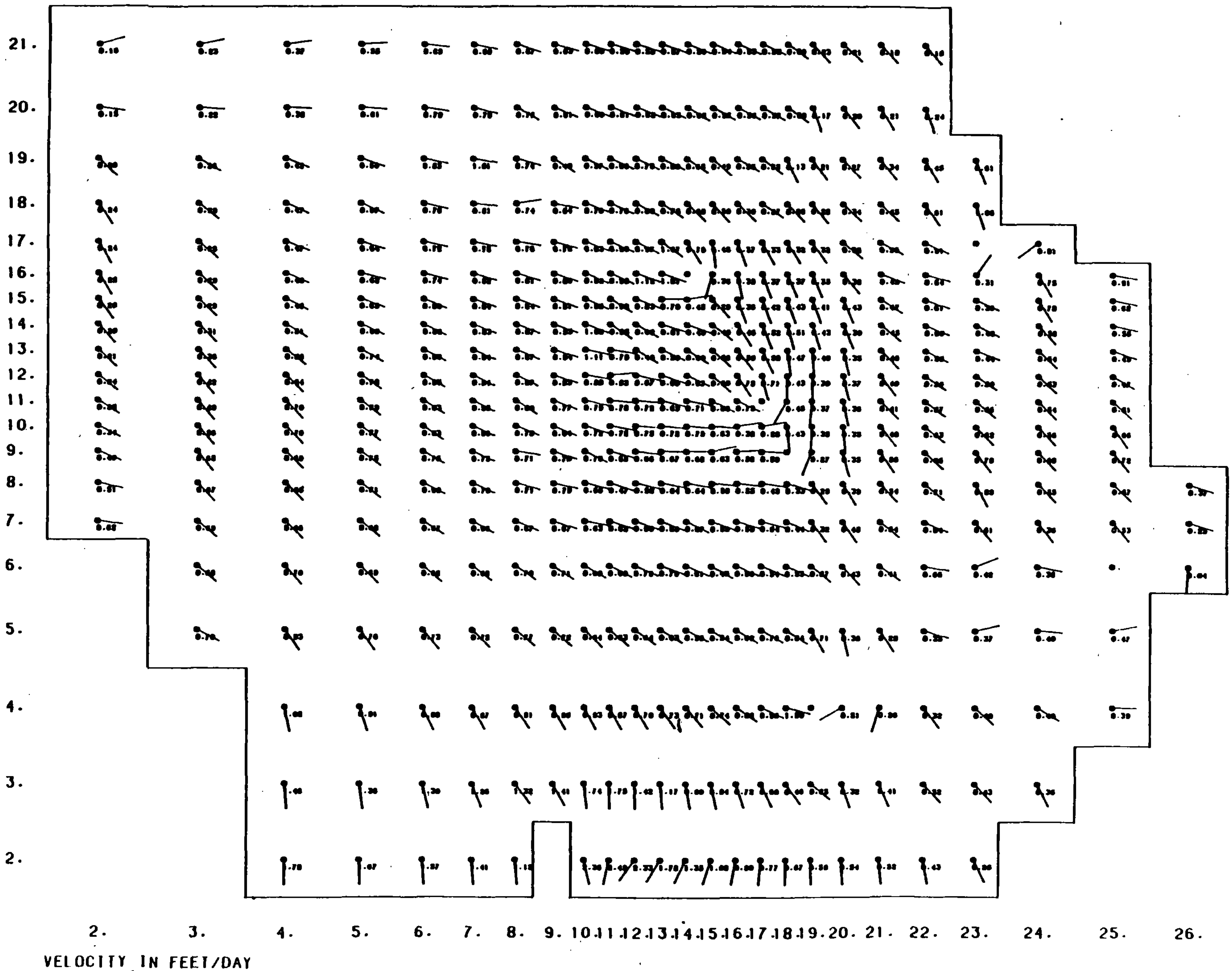
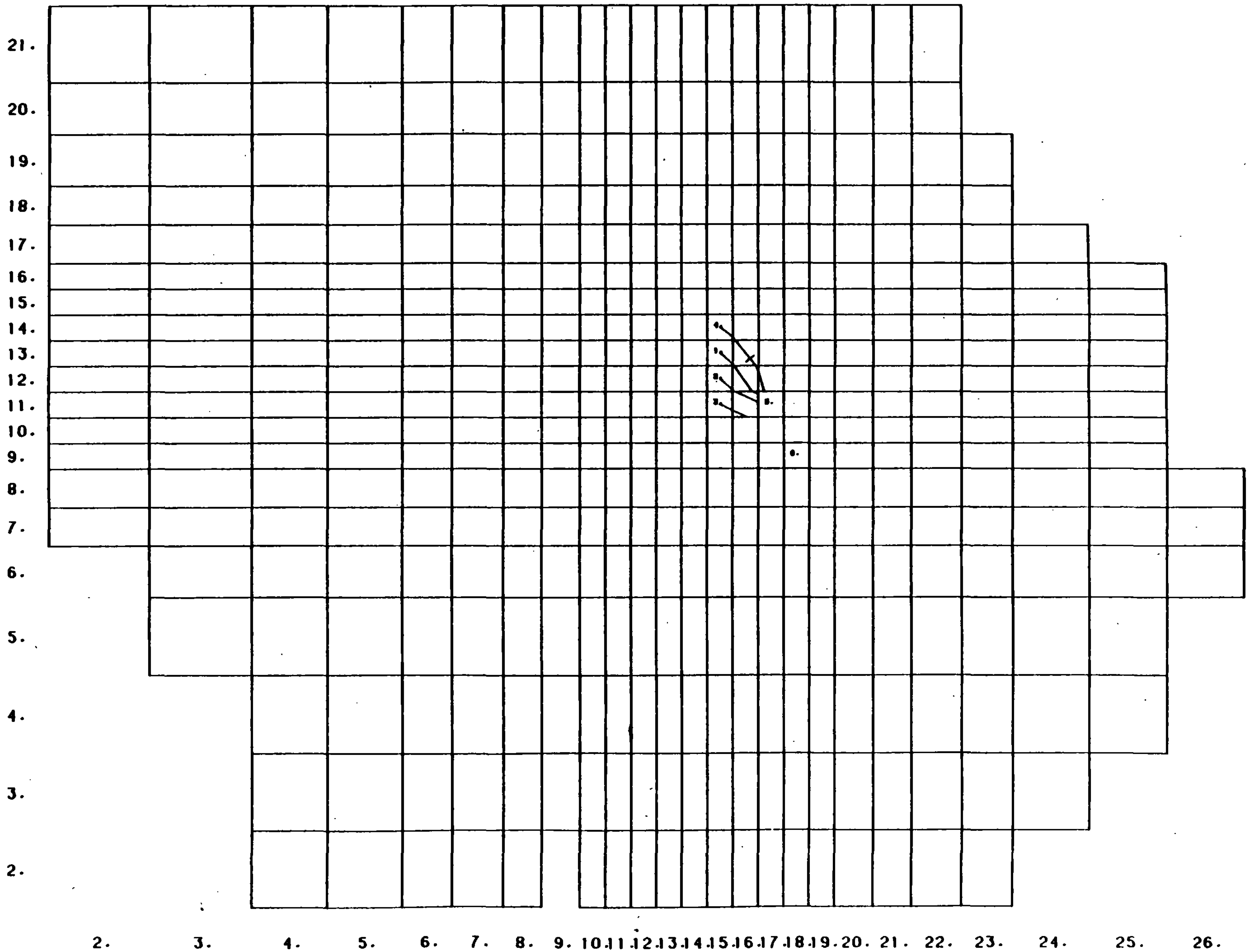


Figure 15 Simulation R3 Predicted Travel Paths in Model Layer 3



TRAVEL TIME TIC INTERVAL = 25. YEARS

Figure 16 Simulation R4 Predicted Flow Pattern in Model Layer 3

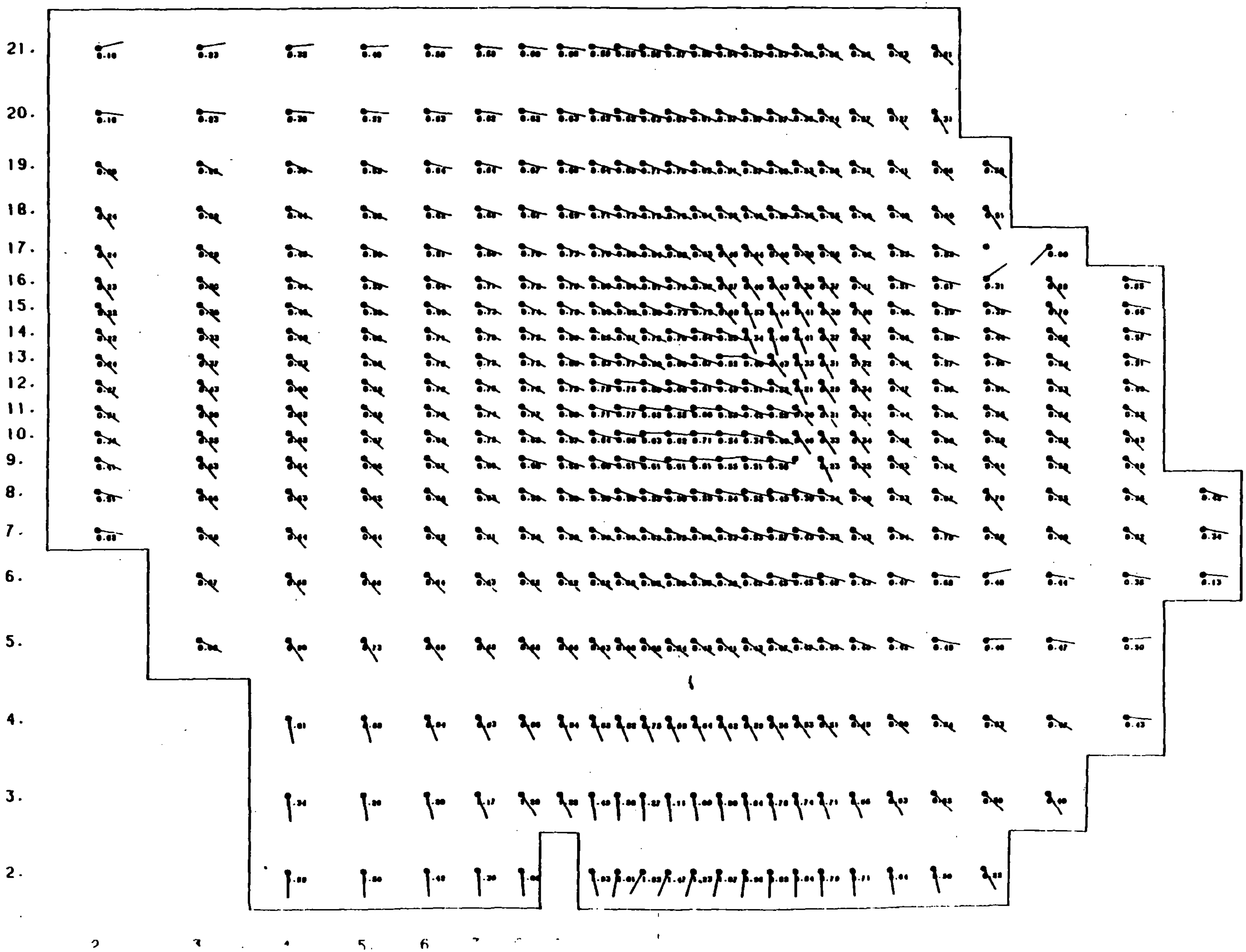


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Figure 17 Simulation R4 Predicted Travel Paths in Model Layer 3

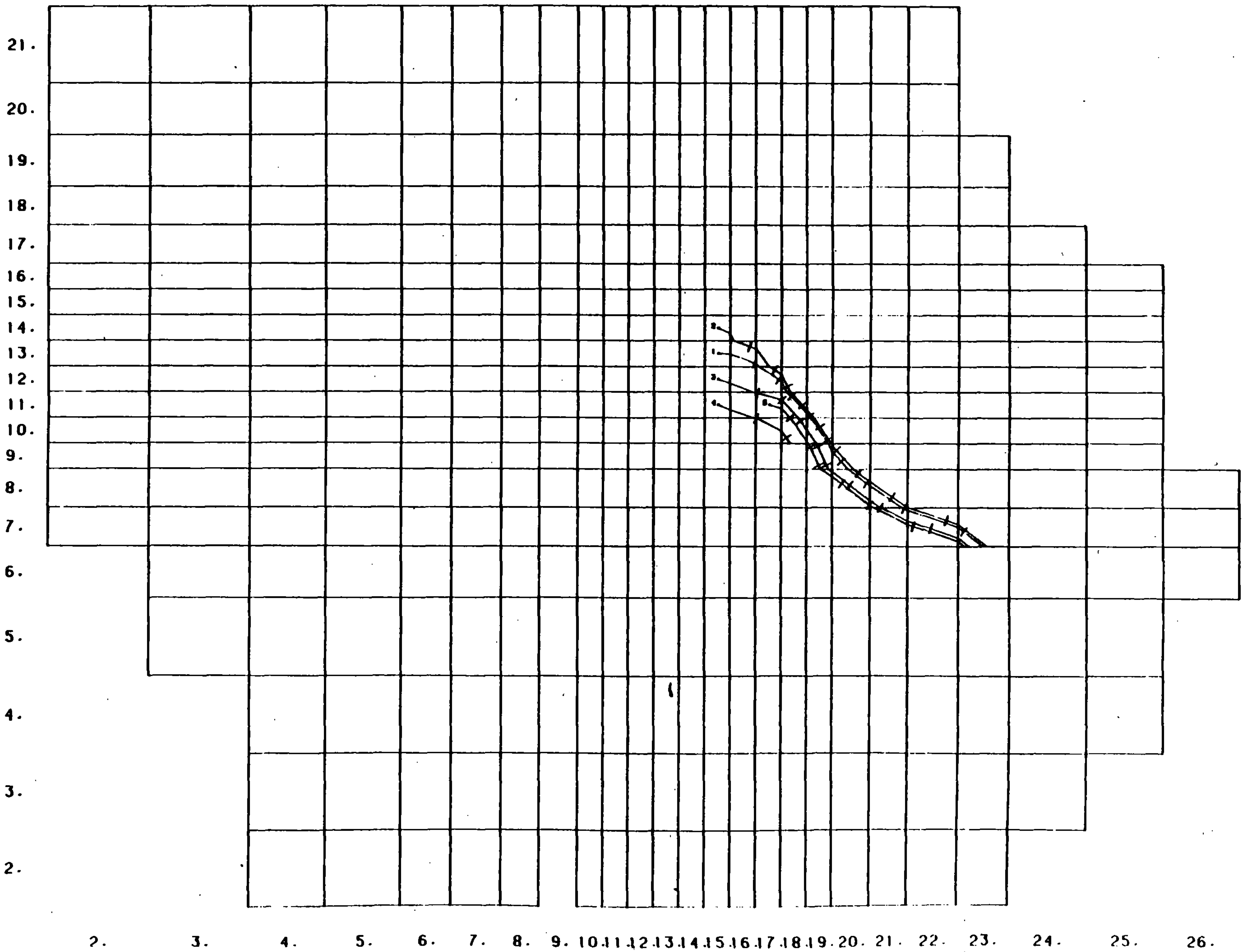

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Figure 18 Simulation R5 Predicted Flow Pattern in Model Layer 3

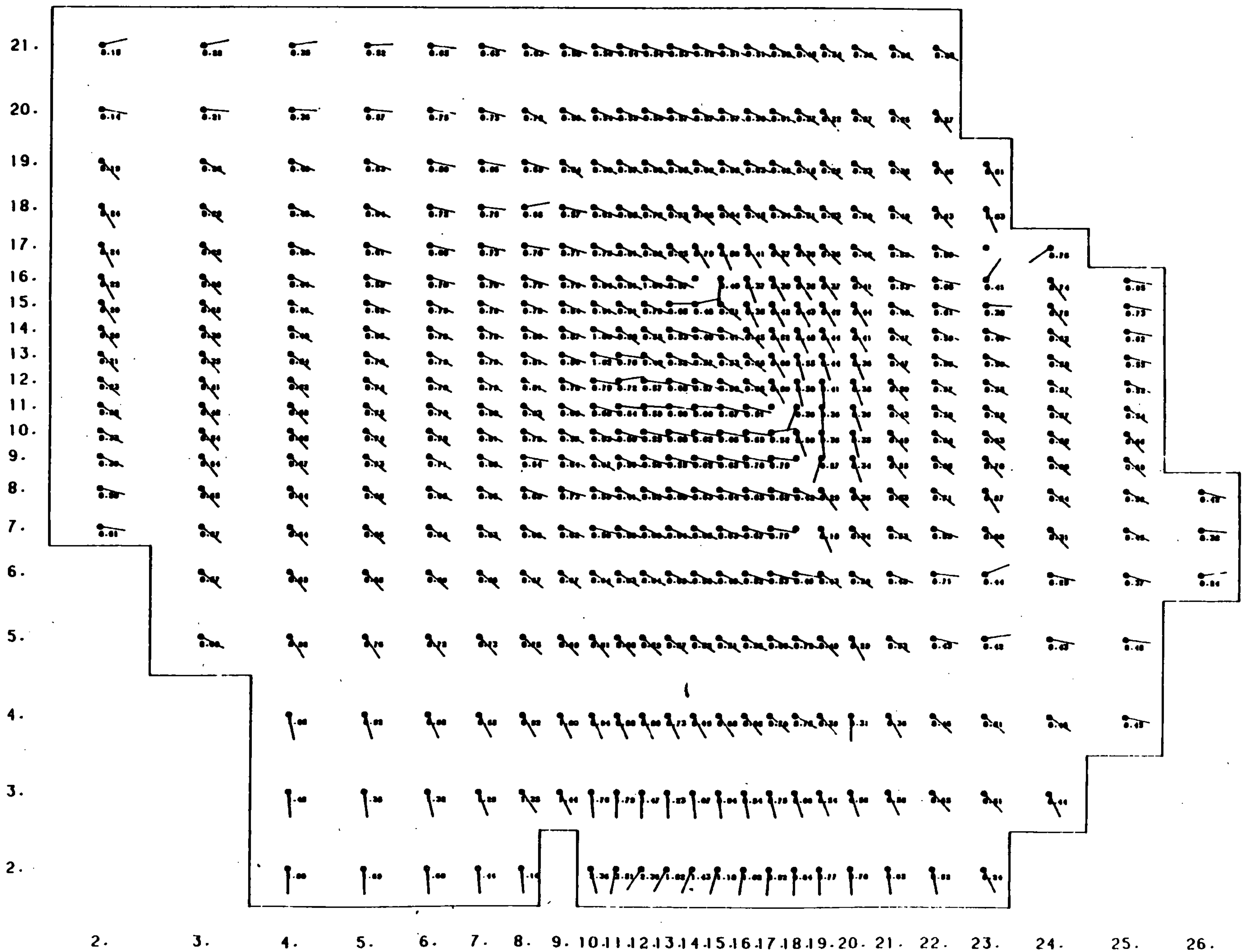

Figure 19 Simulation R5 Predicted Travel Paths in Model Layer 3

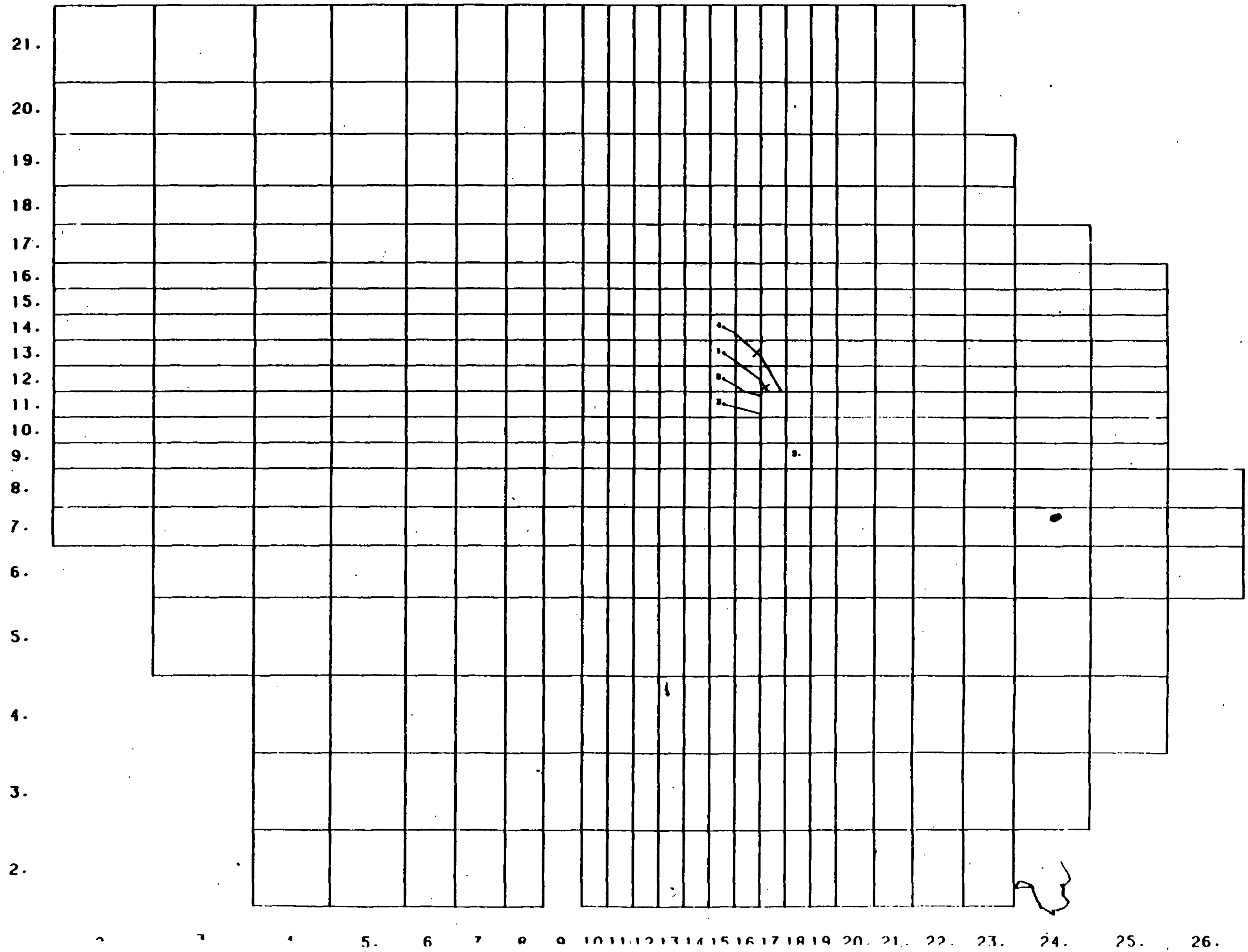

Figure 20 Simulation R6 Predicted Flow Pattern in Model Layer 3

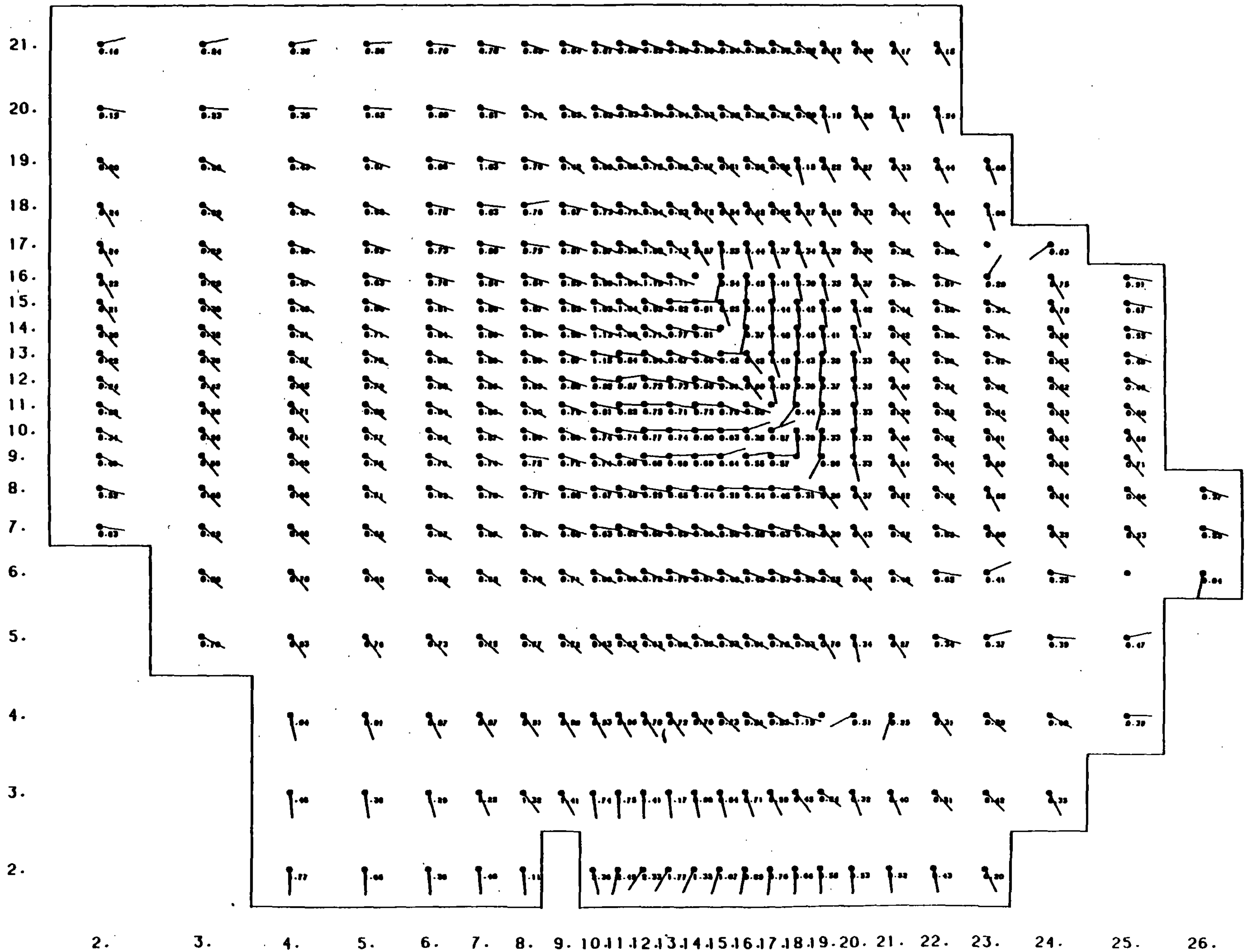

Figure 21 Simulation R6 Predicted Travel Paths in Model Layer 3